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A COMBAT SIMULATION ANALYSIS OF AUTONOMOUS LEGGED UNDERWATER VEHICLES

by

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June, 1996

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Duplicating the MCM portion of the Kernel Blitz 95 exercise whenever feasible, this thesis uses the Janus interactive combat wargaming simulation to model and evaluate the effectiveness of the ALUV as a MCM. Three scenarios were developed: an amphibious landing through a minefield using no clearing/breaching; an amphibious landing through a minefield using current clearing/breaching techniques; and an amphibious landing through a minefield using ALUVs as the clearing/breaching method.

This thesis compares the three scenarios using landing force kills, cost analysis, combat power ashore, and percentage of mines neutralized as measures of effectiveness.

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A COMBAT SIMULATION ANALYSIS OF AUTONOMOUS LEGGED UNDERWATER VEHICLES

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Autonomous Legged Underwater Vehicles (ALUVs) are inexpensive crab-like robotic prototypes which will systematically hunt and neutralize mines en masse in the very shallow water and the surf zone (VSW/SZ). With the advent of mine proliferation and the focal shift of military power to the littorals of the world, ALUVs have the potential to fill a critical need of the United States Navy and Marine Corps mine countermeasure (MCM) forces.

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I. INTRODUCTION

A. RESEARCH OBJECTIVE

The purpose of this thesis is to evaluate the tactical effectiveness of the Autonomous Legged Underwater Vehicle (ALUV) as a mine countermeasure in the very shallow water (10 to 40 feet) and the surf zone (High Water Mark to 10 feet) relative to current Naval Service - the Navy and Marine Corps - mine countermeasure capabilities for hunting and neutralizing mines in these regions.

B. IMPORTANT NOTE

Throughout the pages that follow, numerous acronyms and abbreviations will be introduced to condense the written text. Appendix A will make reading easier because it presents a central listing of all acronyms and abbreviations. Take a moment to familiarize yourself with its location.

C. MOTIVATION

Marines have been known to crawl and claw their way to the shore in amphibious raids - kicking in the door, as they call it. But widespread use of offshore minefields has produced a hazard that has hampered and, in some cases, prevented the Navy-Marine Corps team from conducting amphibious operations of all types.

For example, Iraqi mines strewn throughout the Persian Gulf during the Gulf War posed one of the greatest concerns to allied naval forces. Two United States warships struck mines, damaging both and forcing one to be taken out of action [Ref. 1]. The USS Tripoli,

a helicopter assault ship, which ironically was the flagship for anti-mine operations, hit a mine and suffered a 16 by 20 foot hole in her hull. Another vessel, the USS Princeton, an AEGIS cruiser, set off an influence mine, damaging her propellers and causing a considerable crack in her main deck. The influence mine did not cause a hole, but the damage was so serious the ship had to be towed out of the area and was considered out of action. As a result of these two incidents and because the entire gulf region was more heavily mined than originally anticipated, allied forces determined it too risky to attempt an amphibious landing in Kuwait. Fortunately the naval mines in the Persian Gulf were not a show stopper in the Gulf War conflict. But the success of the United States and allied forces in future conflicts may depend on the force's ability to operate in a maritime environment that is heavily mined.

The Persian Gulf War served as a catalyst which caused the focus of naval power to evolve from the open ocean strategies of the Cold War to the current strategic concept of joint expeditionary operations along the world's littorals. The United States realized the expanded potential of the naval mine to frustrate plans. Consequently, today's Naval Service must have effective mine countermeasures to ensure that post-Cold War era operations can be executed.

D. EVOLVING NAVAL CONCEPTS

1. Forward...From the Sea

The strategic concept and direction of the Naval Service outlined in the September 1992 white paper, titled "...From the Sea," and reaffirmed in its October 1994 companion document, titled "Forward... From the Sea," provide compelling requirements for effective and modern mine warfare forces. The Naval Service must be prepared to operate in distant waters in the early stages of regional hostilities to enable the flow of land-based air and ground forces into the theater of operations, as well as to protect vital follow-on sealift required for delivery of heavy equipment and sustainment of major forces. [Ref. 2]

This combined Navy and Marine Corps strategic concept calls for a forward-deployed naval force, manned, equipped, and trained for combat. This force must provide the means for sea-based reaction should deterrence fail and conflict erupt during a regional crisis. This force, deployed for presence, expeditionary in nature, and reinforced in response to the emerging crisis, must serve as the transition force as the land-based forces are brought forward into theater. Called a Naval Expeditionary Force (NEF), this highly flexible force must conduct a wide range of missions including early forcible entry to facilitate or enable arrival of follow-on forces. [Ref. 3]

NEFs must achieve forcible entry by projecting Marine landing forces (LF) from the sea to objectives ashore in a hostile environment. Marine LFs are composed of versatile, rapidly expandable, and task organized combined arms units. A NEF must reach inland

rapidly, finding gaps in enemy coastal defenses or, if necessary, penetrating prepared beach defenses. If it is necessary to go through prepared defenses, the NEF must perform the myriad of tasks necessary to breach them in-stride. [Ref. 3]

2. Joint Littoral Warfare

The two documents mentioned in the previous section refocus naval strategy towards power projection and naval presence in littoral or "near land" regions of the world. They define littoral as comprising two segments of battlespace. The seaward segment is the geographic area from the open ocean to the shore which must be controlled to support operations ashore. The landward segment is the geographic area inland from the shore that can be supported from the sea. [Ref. 3]

Operations in littoral regions are subject to two characterizations, not necessarily true of open ocean operations, that pose varying technical and tactical challenges. First, the littoral region is characterized by confined and congested water and air space occupied by friends, adversaries, and neutrals, making identification of friend or foe profoundly difficult. Secondly, it is characterized as an area where adversaries can concentrate and layer their defenses. Included, among others, are mine and obstacle defenses which are germane to this thesis. [Ref. 3]

National military strategy calls for joint operations to apply military power across the spectrum of foreseeable situations, including regional conflicts [Ref. 3]. Out of such a mandate arises the need for a force capable of conducting joint littoral warfare. Joint littoral

warfare is the tactical integration of joint and allied forces to influence, deter, contain, or defeat a regional power through the projection of maritime power from the littoral area. It relies heavily on the seamless transition of forces from the sea to the land, a transition that requires a rapid defeat of mine and obstacle threats by joint, integrated amphibious and mine forces [Ref. 3].

3. Operational Maneuver From the Sea

Today's NEF must capitalize on its inherent power, speed, agility, flexibility, mobility, and self-sustainment to project power ashore using the principles of maneuver warfare. The adaptation of this warfare style and its principles to a maritime campaign is termed "operational maneuver from the sea" or OMFTS. [Ref. 3]

The goal of OMFTS is to seamlessly and continuously project combat power ashore, ensuring the rapid attainment of campaign objectives. OMFTS represents not a single technique but a philosophy and a guide for current and future power projection ashore. OMFTS demands rapid and flexible means to break the cohesion and integration of enemy defenses, mine and obstacle defenses included. If mine defenses cannot be avoided, their neutralization is accomplished to avoid interruption of the seamless and continuous nature of the operation. Thus, OMFTS places flexibility constraints on mine warfare operations to assure the smooth transition of forces from sea to the objectives. [Ref. 3]

4. Over-the-Horizon Amphibious Operations

Integral to the concept of OMFTS is the concept of over-the-horizon (OTH) amphibious operations which uses technology advances to improve the opportunity for tactical surprise. An OTH operation is an amphibious assault initiated from beyond the visible and radar horizon. [Ref. 3] Under the concept of OTH amphibious operations, Landing Crafts Air Cushioned (LCACs) and Amphibious Assault Vehicles (AAVs) deliver the LF across the very shallow water and the surf zone (VSW/SZ).

To enhance such an operation, discovery of enemy weak points is desirable. SEAL Survey Teams provide the current covert means of enemy weak point discovery in littoral regions. Such covert operations expose the personnel involved to grave physical risks and require an inordinate amount of time to complete. Technology advances may provide a better approach to solving this problem, while limiting hazards to personnel and expediting the overall discovery process. Although discovery of gaps in the enemy's mine and obstacle defense is desirable, the in-stride breaching of those defenses to facilitate the surface assault may be necessary.

5. In-Stride Mine and Obstacle Breaching

In-stride mine and obstacle breaching supports the rapid neutralization of mines and obstacles necessary to make seamless joint littoral warfare, OMFTS, and OTH operations possible. In-stride breaching requires mine and obstacle clearance or neutralization systems which can be employed immediately preceding initial surface assault waves through the

VSW/SZ without impeding the progress of the landing. Effective in-stride breaching eliminates delays that LFs often encounter and minimizes the potential for losing the element of surprise. [Ref. 3] Current measures intended to facilitate in-stride breaching fall short because they limit the element of surprise. Any technique or technological development that promotes unobtrusive mine and obstacle clearing will find considerable utility.

E. THE LITTORAL MINE PROBLEM

1. Forcible Entry is the Law

The United States Naval Service is required by law to possess the capability to effect a forcible entry onto a defended shore by means of amphibious assault. Current defense planning guidance reaffirms the operational requirement for this capability. The global maritime military strategy has evolved to focus on regional challenges with the complexities of conducting military operations in littoral areas, the battlespace of amphibious operations. An amphibious assault has as its goal the rapid build-up of combat power ashore, from an initial level of zero, to fully coordinated striking power capable of successfully achieving objectives ashore. It is a difficult mission and the littoral battlespace is a complex environment. [Ref. 3]

Potential regional adversaries have developed sophisticated anti-landing doctrines employing modern weapons and tactics. A key principle of OMFTS is the avoidance of enemy defenses. However, the ability to breach coastal, anti-landing barriers consisting of

mines, obstacles, and covering fires, when avoidance is not possible, remains a critical capability within forcible entry. [Ref. 3]

2. Mines in the Battlespace

Mines are cheap and available. It is wise to expect that every enemy will have the resources to employ them, and that any coastal adversary will employ at least some as anti-landing weapons. Even those foes without the capability to deploy extensive and sophisticated maritime and littoral defensive fields will use mines as weapons of intimidation and as a means to occupy the resources of a more powerful antagonist. [Ref. 4]

Good naval mines are moderately expensive, but against high value targets can be especially cost effective. A prepared and determined foe can be expected to use them against allied ports and shipping lanes, as well as in his own or captured territory. Because few adversaries either expect or strongly desire to use extensive maneuver on the seas against the United States, they can achieve effective battlespace dominance by restricting use of the seaward approaches to theater littoral. This fact makes even crude maritime mining a potentially effective weapon in the hands of foes. [Ref. 4]

The enemy makes extensive use of mines and obstacles as counter-mobility weapons in the areas of an anticipated landing. Mines and obstacle defenses are designed to thwart littoral power projection by channeling, blocking, or deflecting assault forces in order to concentrate the battlespace; and to disrupt and delay the LF's operational tempo during critical phases of the operation.

3. Inadequate Mine Countermeasures

Succinctly defined, mine countermeasures (MCM) include all methods for preventing or reducing damage or danger from mines [Ref. 3] . Current MCM capabilities are limited by inadequate integration of assets, minimal reconnaissance means (especially clandestine), and operational pauses created by the slow, deliberate nature of MCM operations. Specifically, the critical limitations are [Ref. 4]:

- Current countermine capabilities cost the advantage of surprise and relative operational speed. Limitations in clandestine reconnaissance and preparation "tip our hand" early to the enemy. Limitations in capability to conduct truly rapid breaching once beginning offensive operations cede additional tactical advantages to the enemy.

- Range limitations in ship to shore assets require that naval forces either launch landing forces from close proximity to the beach, or land surface forces by LCAC in an area which must be isolated sufficiently to allow for an extended build up of maneuver forces in a beach area. This latter area may be far from critical objectives and the vulnerabilities that joint littoral warfare seek to exploit.

- Maneuver limitations in surface ship to shore assets limit the ability to exploit gaps in the defense. Even when launched from close inshore, LFs are limited to nearly linear movement until ashore. Utilizing only LCACs solves some of this problem, but reintroduces the loss of tempo associated with the build up time requirements in the beach area.

The result is that an enemy who can emplace mines in operationally significant littoral locations has at least partially succeeded in his objectives.

F. POSSIBLE SOLUTION TO THE LITTORAL MINE PROBLEM

1. Many-Robot MCM Approach

MCMs near coastlines, both before invasions and soon after, remains a difficult problem for naval forces around the world. In order for an amphibious force to successfully reach the shore, a breached lane 50 yards wide must be cleared through the VSW/SZ with a high degree of reliability and in a limited amount of time. [Ref. 5] This situation is complicated by the fact that small mines can be laid in large numbers, for example by air drop. The situation is further complicated by the harsh environment; particularly in the VSW/SZ, many existing systems simply cannot function. Not only is the water perilously shallow in these regions, but acoustic noise and turbidity hamper mine detection. A possible solution to this problem is to employ a large number of small, inexpensive, expendable robotic units that crawl on the ocean bottom, hunting and neutralizing mines. Such a system comprising a large number of identical and inexpensive vehicles is more robust than a system that relies on a very few complex vehicles, as mission success is not impacted by the loss of a reasonable percentage of units. Additionally, satisfactory area coverage can be accomplished in part by the sheer number of vehicles rather than a requirement of systematic, thorough, time-consuming search [Ref. 5].

In many respects, MCM operations appears to be perfectly matched to the many-robot systems concept [Ref. 6]:

- The MCM environment is dangerous to humans; a robotic solution allows MCM operators to be physically removed from the hazardous area.

- The MCM environment is also dangerous to machines; the use of multiple inexpensive robotic search elements minimizes the cost of lost system assets, and allows the mission to be performed by the remaining elements.

- One important MCM task is the destruction of mines; using very cheap, deliberately expendable elements allows a one-element-per-mine approach.

- Many mines must be dealt with; the use of many robots allows these targets to be prosecuted in parallel, rather than one at a time.

The many-robot approach promises improved mine detection and clearance capabilities and becomes increasingly viable as continuing technological developments provide these capabilities at ever decreasing costs.

2. Autonomous Legged Underwater Vehicles (ALUVs)

Funded by the Advanced Research Projects Agency and the Office of Naval Research, Rockwell International, IS Robotics, and the University of California at Berkeley are jointly developing Autonomous Legged Underwater Vehicles (ALUVs) for VSW/SZ mine hunting and en masse neutralization [Ref. 7]. See Figure 1.

The ALUV pays tribute to a crustacean that thrives in the VSW/SZ. A crab scuttles through the VSW/SZ on legs that can dig in when the waves get rough. The ALUV can also weather severe surf, burying itself in the sand by vibrating its legs.

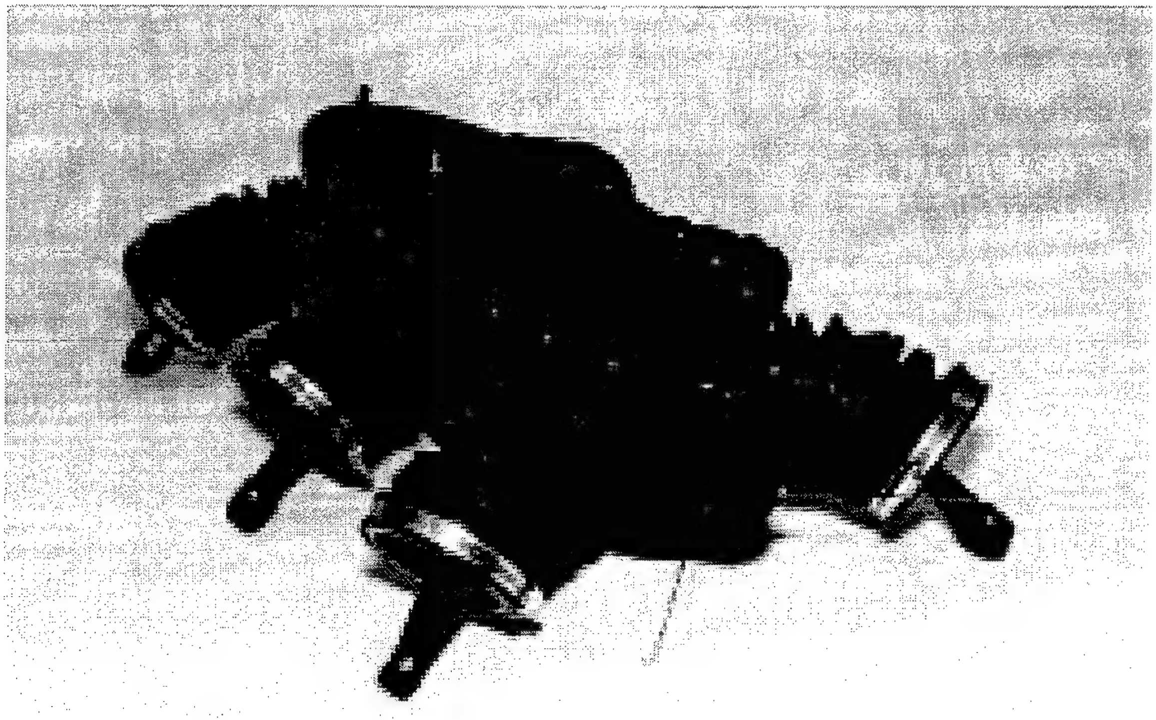

Figure 1. Autonomous Legged Underwater Vehicle (ALUV)

What's more, legs are great structures to load with sensors, because they touch whatever they walk on. When the ALUV chances upon a mine, it clings to its quarry and then awaits a command from an operations center aboard a landing craft offshore. Once the signal is given, each ALUV blows itself - and the mine - up. [Ref. 7]

The ALUV is described in more detail in Chapter II, Section C, Subsection 7 of this thesis. Reference 17 also contains a wealth of information on the ALUV.

G. RESEARCH METHODOLOGY

Using the Janus(A), version 3.15, combat simulation computer model, the researcher seeks to evaluate the tactical effectiveness of the ALUV as a MCM in a simulated littoral region and to compare the ALUV to current Naval Service littoral MCM capabilities.

Written in FORTRAN and adapted for use with the UNIX operating system, Janus is a high resolution, interactive, two-sided, closed, stochastic, ground combat simulation [Ref. 8]. This high resolution model allows the user to create units as small as individual infantry and vehicular weapon systems and place these systems in ground combat scenarios where the focus of the simulation is on the maneuver of the systems either individually or as elements of larger units. The scenarios developed are two-sided, placing two forces, Blue and Red, in opposition to each other. The simulation is closed so that the disposition of one opposing force is unknown to the other until force locations are disclosed through direct observation and contact or through intelligence reports generated by friendly forces. It is interactive because it allows the user to make changes in the scenario as events unfold without stopping the simulation. Finally, stochastic refers to the way the system determines the result of actions like direct fire engagements or minefield crossing events: according to the laws of probability and chance. For a detailed description of Janus, see Reference 8 and Reference 9.

H. ORGANIZATION

This thesis is organized into four chapters, including this Introduction. Chapter II addresses model assumptions and describes the development of the three Janus scenarios used in this thesis. Chapter III presents a statistical analysis of the numerical data results obtained from the scenarios. Chapter IV gives a summary of the conclusions and recommendations drawn from this research.

II. MODEL DEVELOPMENT

A. THE SETTING

Under mellow sunshine and a balmy climate along the southern California coast, there is a vast expanse of hills and valleys known as Camp Pendleton. Named in honor of Major General Joseph H. Pendleton who pioneered Marine Corps activities in the southern California area during his 46 years of distinguished service, Camp Pendleton has developed into the Corps' largest amphibious assault training facility. Purchased by the government in 1942 at a cost of $4,239,062, this 125,000 acres of real estate and accompanying 17 miles of prime coastline is now populated by more than 34,000 Marines and sailors and provides training facilities for many active and Reserve Marine, Army, and Navy units [Ref. 10]. It is here that the Navy and Marine Corps join forces to conduct a biennial training exercise dubbed Kernel Blitz.

B. KERNEL BLITZ

The objective of the Kernel Blitz exercise is to improve the ability of a NEF to operate effectively, as a total force, in a littoral environment [Ref. 11]. The exercise provides an excellent opportunity to showcase amphibious and expeditionary force training emphasizing "Forward...From The Sea" strategy and littoral warfare missions. Canada, Belgium, Holland, France, Germany, Italy, Norway, Sweden, and Korea are but a few of the countries that send official representatives to observe the exercise. Kernel Blitz is an umbrella exercise that contains a series of subordinate exercises intended to [Ref. 11]:

- Demonstrate the scope and flexibility of projecting combat power ashore under realistic hostile conditions by conducting a large scale amphibious landing.

- Demonstrate the unique capability of Navy medicine to support expeditionary forces in a hostile environment, including triage, medical evacuation, and afloat medical care.

- Demonstrate current capabilities and new initiatives in the area of MCMs.

- Demonstrate current capabilities and potential usefulness of wargaming and simulation technologies to enhance the training of Navy and Marine Corps forces.

The scenarios contained within this thesis duplicate, whenever possible, the efforts of the forces involved in the Kernel Blitz 95 exercise as outlined in Reference 15. Furthermore, the author has concentrated the combat modeling and simulation effort only on the MCM portion of the exercise.

C. JANUS SCENARIOS

1. Introduction

This section contains a specific explanation of the development of the amphibious combat operation for this thesis. Following the overview, the map and scenario weather data sources are briefly discussed. The defensive minefield structure is then outlined in some detail, followed by the force structure of the offensive force. The offensive force is presented in three distinct scenarios.

2. Overview

OTH operations call for an approximate 20 nautical mile distance from ship to shore; however, the defensive force's ability to detect, target, and attack the LF is the key determinant of the OTH distance. As the LF assault unfolds, the defensive force's abilities often become degraded to a point where OTH operations can be conducted at distances much closer than 20 nm. [Ref. 12] The scenarios contained herein assume that the OTH operation is conducted at 1200 hours, at low tide, from a distance of 20 nm from the Camp Pendleton coastline. What's more, it is assumed that the LF (Blue Janus Force) goes undetected by the defensive force (Red Janus Force) ashore because the LF commander has maneuvered his LF to Red Beach, a strike location that is neither anticipated nor discovered by the defending force. The LF does encounter one problem, a littoral minefield in the VSW/SZ. The author realizes that rarely will a LF go undetected and that minefields almost always are covered by direct fire weapons, but to concentrate the modeling effort on LF versus minefield, the author has made these assumptions. Figure 2 , an adapted version of a diagram in Reference 12, gives a panoramic view of the amphibious objective area (AOA).

3. Camp Pendleton Map and Weather

The modeled scenarios use digitized terrain of Camp Pendleton developed from Defense Mapping Agency data, displaying it in a form familiar to military users with terrain contour lines, roads, rivers, vegetation, and urban areas [Ref. 9]. Janus additionally simulates the effects of light and weather. All of the mentioned factors affect the movement,

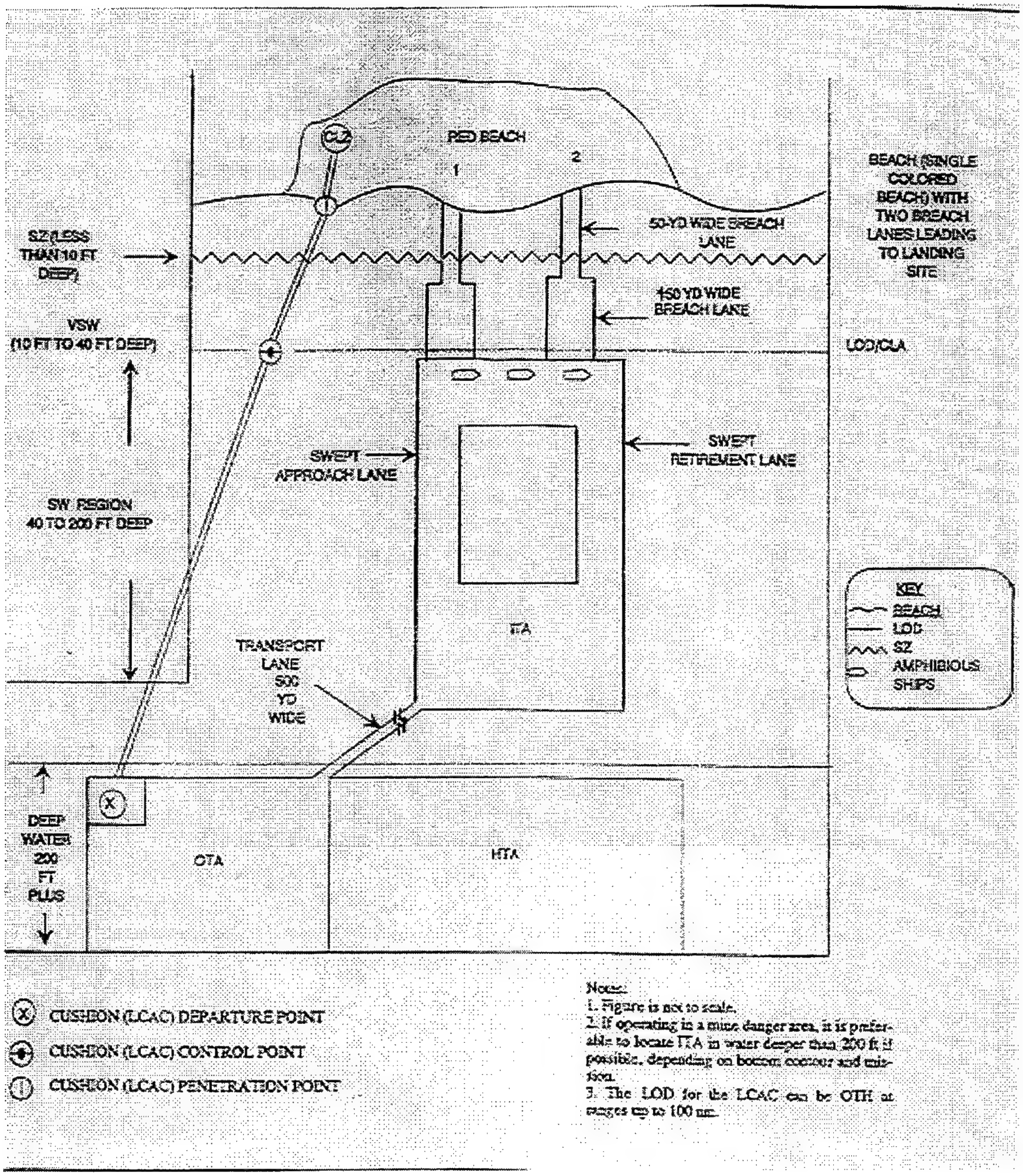

Figure 2. Overview of Amphibious Objective Area off the Coast of Red Beach

visibility, and target acquisition of the systems developed within Janus. Therefore, as in real life, these considerations must be taken into account when planning a Janus scenario. An image of the Janus representation of Camp Pendleton is contained in Appendix B.

4. Mines, Minefields, and Densities

a. Mine Types and Employment Depths

Naval mines are developed for specific purposes and can be used to complicate all phases of an amphibious warfare operation, including its supporting MCM operations. Laying large minefields that are effective requires placing mines in a linear fashion of some sort to reduce the possibility of gaps [Ref. 13]. The defensive force in this thesis employs a three layer linear minefield defense consisting of pressure mines in the SZ, tilt-rod mines in the VSW/SZ, and magnetic influence mines in the VSW. An influence mine is a mine actuated by the effect of a target on some physical condition in the vicinity of the mine or on radiations emanating from the mine. A tilt-rod mine is an anti-landing mine actuated by direct pressure against a rod causing it to tilt to a set limit. A pressure mine has circuits which respond to the direct pressure or the hydrodynamic field of a target. [Ref. 12] Water depth was used as a context for categorizing the types of mines laid in particular regions. The mines were laid in a linear fashion, and the corresponding mine types and depths are depicted in Figure 3.

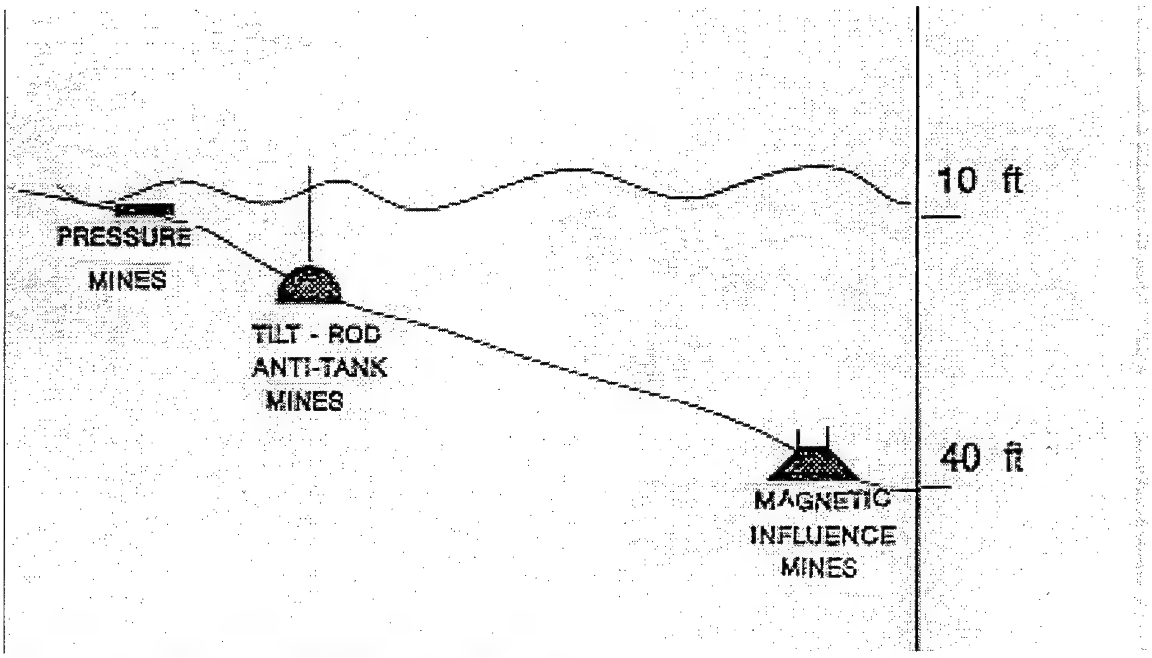

Figure 3. VSW and SZ Mines by Depth

b. Janus Minefields

Janus simulates five types of minefields: hand emplaced, ground vehicle emplaced, artillery emplaced, helicopter emplaced, and a manually operated portable minefield. Only one type of mine can be specified for each type of minefield. The Janus code allows for a maximum of fifty minefields, provided the total number of mines does not exceed forty thousand. [Ref. 8] By adjusting the data base probabilities associated with each mine type, a Janus user can model various types of land and naval mines. In the scenarios developed for this thesis, the hand emplaced (HAND EMP) mine type represents magnetic influence mines (MGM), the ground vehicle emplaced (MECH-1) mine type represents tilt-

rod mines (T-RM), and the helicopter emplaced (MECH-2) mine type represents pressure mines (PM). The placement of mines within a minefield is randomly generated by the computer each time a scenario is run.

A single HAND EMP minefield consists of 99 mines placed regularly in a 50 by 100 meter rectangle. The mines within this minefield are located in three strips of 33 mines each. The three strips are 15 meters apart. Within a single strip, the mines are placed every 3 meters, alternating on either side of an imaginary line which bisects the strip. HAND EMP minefields are located and emplaced by the user during the initial planning of a scenario. Once in place, the user can execute multiple runs of a scenario without altering the placement of HAND EMP minefields. The number of HAND EMP minefields is generated by entering the desired number of HAND EMP minefields into the Mine Type 1 field on Janus screen III.

MECH-1 emplaced minefields consist of mines that are uniformly distributed in both length and width within a rectangular area. The density of mines dispensed is selected by the user as either low (40 mines), medium (80 mines), or high (160 mines). Although the length and width of this minefield can be altered, the number of mines is hard-coded. MECH-1 minefields are positioned and oriented by the user during scenario initial planning or during scenario execution. The number of MECH-1 minefields is generated by entering the desired number of MECH-1 minefields into the Mine Type 2 field on Janus screen III.

The MECH-2 minefield is positioned and oriented by preplanning a helicopter movement route over the minefield site and dropping the MECH-2 minefield at the desired location. The user decides when to drop each minefield from the helicopter and executes a drop interactively with a computer mouse. The mines within the MECH-2 minefields are randomly but uniformly distributed within the minefield dimensions. The densities are selected in the same way as that of MECH-1.

Minefield classifications are defined by the user within the Combat Systems Data Base, as are each system's vulnerability to each minefield type. The assignment of a breaching capability to an individual system is made within the Force Definition File of Janus. However, the effectiveness of each breaching method (e.g., plow, roller, line charge) is assigned within the Combat Systems Data Base. Each breaching method is assigned a survival probability specifying the likelihood that a MCM system will survive given that it encounters a minefield. For example, a mine breaching plow attached to a tank may be assigned a 79 percent chance of successfully neutralizing an influence mine (method effectiveness), but only a 75 percent chance of surviving given that it encounters an influence mine (method survivability). [Ref. 14]

Each system created in Janus is assigned minefield activation and kill probabilities. For instance, a tank might be assigned an 85 percent chance of activating a tilt-rod mine and, if activation occurs, only a 50 percent chance of actually being killed by the tilt-rod mine. Each system is assigned unique minefield activation and kill probabilities for

each mine type that is modeled. Probability assignments specific to this thesis are outlined in Appendix C.

c. Densities

The author designed the minefields in the VSW/SZ such that each of the two breach lanes in Figure 2 contain approximately 179 mines, giving a combined total of approximately 358 mines in the VSW/SZ.[1] Each lane contains approximately 99 magnetic influence mines, 40 tilt-rod mines, and 40 pressure mines.

5. Bull Breaching Scenario

The Bull Breaching Scenario serves as a benchmark to gauge the relative effectiveness of the other two scenarios, the Traditional Scenario and the ALUV Scenario. The Bull Breaching Scenario simulates an amphibious landing through mined littoral zones without breaching operations being conducted prior to the assault. This scenario should demonstrate the devastating effect that a minefield can have on a force that proceeds through a minefield prior to clearing and emphasize the need for effective MCMs. The basic LF used in all three scenarios is outlined in Reference 15 and consists of 23 AAVs (Figure 4), 9 LCACs, and 11 LCUs. The AAVs are split into two distinct task forces, the first consisting of 11 AAVs and the second consisting of 12 AAVs. The reference dictates that the LCUs

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[1]The numbers 179 and 358 may seem arbitrary, but they are not. Janus has hard-coded densities for the minefield emplacement methods selected for this thesis, so the author used the minimum number of mines that can be represented by three distinct Janus minefields. Adding 99, 40, and 40 gives 179. Because each scenario requires an ingress and an egress lane, the total number of mines doubles from 179 to 358. Each lane contains 179 mines.

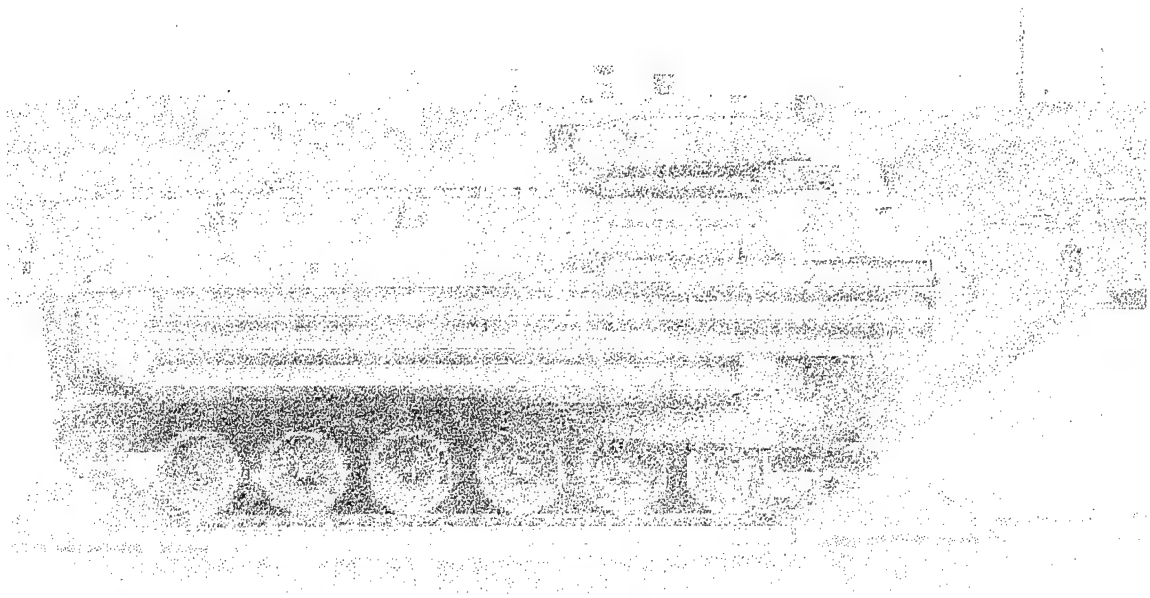

Figure 4. Amphibious Assault Vehicle (AAV)

will transit the breach lanes only if required. To standardize the three scenarios, the author has assumed that no LCUs will transit the breach lanes. To eliminate variability and bias in the movement routes of the basic LF in each scenario, the author preplanned all force movements in the Bull Breaching Scenario and copied this scenario into the two additional scenarios.

The sequence of events in the Bull Breaching Scenario follow. Please refer to Figure 2 as necessary.

1. A defensive force helicopter drops mines in the SZ.

2. Simultaneously, the AAV task forces transit from the ITA to the CLZ through the mined littoral zone lanes in column formation.

3. The LCACs ingress in column formation from the OTA through lane 1 and egress to the OTA through lane 2.

The data generated from this scenario will serve as a baseline for comparative analysis with the other scenarios of interest. The Bull Breaching Scenario is scenario number 681 within the Janus database.

6. Traditional Scenario

Kernel Blitz 95 served as a test ground for the MCMs used in the Traditional Scenario. This scenario incorporates a current MCM technique (Figure 5) and a developmental MCM technique that has not been employed in a real life situation, but

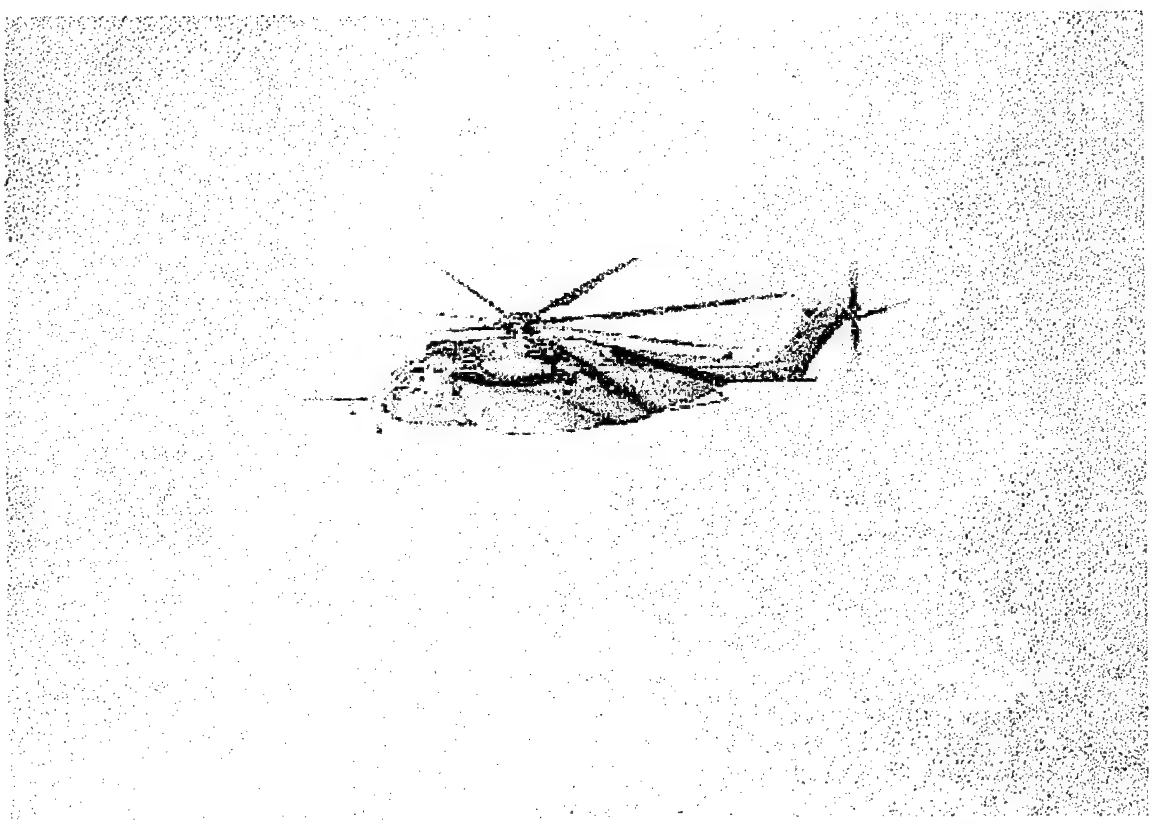

Figure 5. MH-53 in Action

received positive reviews from Kernel Blitz 95. If a littoral warfare contingency occurred today, the techniques in this scenario could be fielded in tandem to conduct in stride breaching operations. Although the Naval Service currently has the MCM capabilities of this scenario, these two techniques would certainly limit the momentum of the attack and sacrifice the element of surprise. Perhaps the conclusions drawn from this research will help to validate or invalidate Kernel Blitz 95 lessons learned as they pertain to the breaching techniques contained herein.

The sequence of events for the Traditional Scenario follow. Please refer to Figure 2 as necessary.

1. A defensive force helicopter drops mines in the SZ.

2. Four MH-53E Sea Dragon helicopters towing Mk 105 magnetic sweep hydrofoils transit from the HTA to the VSW to counter the magnetic mine threat in the VSW. These helicopters return to the HTA after completing their mission.

3. Two LCACs, one per lane and each containing 12 M-58 line charges (Figure 6), transit simultaneously from the ITA to the shore breaching a lane in the SZ.

4. Simultaneously, the AAV task forces transit from the ITA to the CLZ through the mined littoral zone lanes in column formation.

5. The LCACs ingress in column formation from the OTA through lane 1 and egress to the OTA through lane 2.

The Traditional Scenario is scenario number 682 within the Janus database.

Figure 6. LCAC Firing M-58 Line-Charge

a. Modeling Systems in Janus

With the exception of the LCACs that contain the M-58 line charges, all systems introduced in the Bull Breaching Scenario and the Traditional Scenario were resident within the Janus data base. To learn more about the development of the AAV, the LCAC, and the MH-53-E with attached Mk 105, see References 14 and 16. The LCACs that contain the M-58 line charges were developed by simply adding a minefield breaching capability to the LCAC contained in the data base. The Force File in Janus allowed the author to add the 12 line charges to the LCAC.

7. ALUV Scenario

To give a one-to-one ratio of ALUVs to mines, the ALUV Scenario pits 358 mines against 358 ALUVs. Recall that the ingress and the egress lanes each contain 179 mines. This scenario is of particular interest because it simulates the MCM that motivates this research.

The sequence of events for the ALUV Scenario replicate those in the Traditional Scenario, except events 2 and 3 in the Traditional Scenario are replaced by:

- 179 ALUVs transit each lane from the ITA through the VSW/SZ 26 end-to-end passes before returning to the ITA. Note that those ALUVs that locate mines will not return to the ITA.

The ALUV Scenario is scenario number 683 within the Janus database.

a. Modeling the ALUV in Janus

In Janus, a system is a platform which carries from zero to fifteen weapons and is assigned one or more sensors which allow it to acquire enemy systems during combat simulation execution. A system has a number of characteristics defined in the Combat Systems Data Base that establish how the system will operate in the simulation (e.g., speed, weight, carrying capacity, fuel capacity, movement type, etc.). This section will describe the ALUV in more detail and address the development of the ALUV within the Janus data base.

An ALUV is a battery powered robot that can walk underwater, autonomously survey a VSW/SZ region, detect mine-like objects, and carry enough explosive to neutralize a mine. Elliptically shaped and approximately 6.5" wide by 22.5" long by 3" high, it has a one piece waterproof derlin body and 6 externally mounted 2-degree-of-freedom legs. Internal sensors allow the legs to sense obstacles and to walk over them. Pressure sensors around the body enable the ALUV to sense fluid flow and tilt its body into the flow to maintain stability.

ALUVs operate without central control and largely independently of one another. Collectively, they systematically achieve a large scale goal of area search with little or no interaction. Each ALUV searches independently using inexpensive, on-board sensors (a compass and a depth sensor). Based on the known bearing perpendicular to the beach, it walks toward the beach until it reaches a minimum depth, then turns 180° and walks out to a maximum depth and again turns 180°. If two ALUVs approach one another, they detect

each other's presence (by a short range directional acoustic pinger) and veer apart. In this way, the collection of ALUVs first spread out into a uniformly spaced search pattern, and then systematically searches the landing zone without unnecessary duplication. [Ref. 17]

Because an ALUV walks along the surface of the ocean floor, it could be modeled best as a Janus amphibious footed dismounted system. To develop the ALUV within Janus, the author first drew a graphic to represent the system. See Figure 7. Each graphic can be aggregated to represent more than one ALUV, and a tactical dispersion distance for

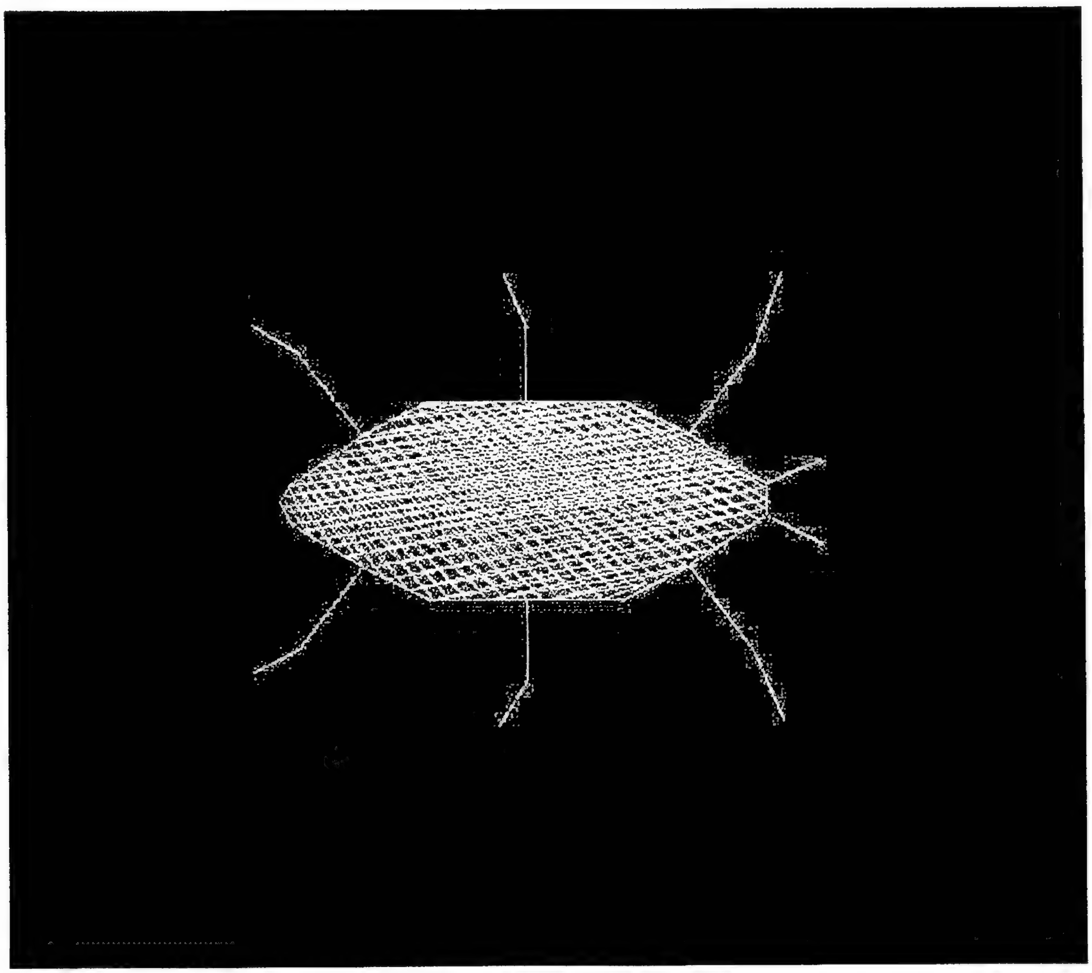

Figure 7. Janus Graphic Representation of an ALUV

these aggregated systems can be established. To maintain the one-to-one ALUV to mine ratio, the author aggregated the graphics to represent 358 ALUVs, 179 per lane. The tactical dispersion distance was established as approximately 4.6 meters by using the following formula obtained from Reference 17:

$$\boldsymbol{r} = \frac{\boldsymbol{W}}{0.74 * \sqrt{\boldsymbol{f} * \boldsymbol{M}}} \tag{1}$$

$\boldsymbol{M}$ represents the expected number of mines, $\boldsymbol{W}$ represents the width of the landing zone, $\boldsymbol{f}$ represents the ratio of ALUVs to mines, and $\boldsymbol{r}$ represents the tactical dispersion radius that ALUVs maintain. Recall that the MCMs aim to neutralize 179 mines per lane, so $\boldsymbol{M}$ is 179. Also recall that an amphibious force needs a breached lane 50 yards wide to successfully reach the shore, so $\boldsymbol{W}$ equals 50 yards, or 45.72 meters. The one-to-one ratio of ALUVs to mines dictates that $\boldsymbol{f}$ equal 1.

Janus allows a user to interactively use a computer mouse to plan the routes of systems. Thus, the author preplanned the routes of each ALUV during the initial planning of the ALUV Scenario. To ensure thorough coverage of the two landing lanes, the author used the same logic that the developers of the ALUV use, according to Reference 17. Given a search width $\boldsymbol{w}$ an ALUV covers as it walks, the landing lane width $\boldsymbol{W}$, and the number of ALUVs $\boldsymbol{N}$, one can use Equation 2 to calculate the fraction of coverage of the width of the

landing lane in a single end-to-end pass by the ALUVs, and therefore how many passes back and forth will be needed for thorough coverage:

$$\textit{Fractional Coverage} = \frac{w * N}{W} \qquad \left(\textit{For } \frac{w}{W} < N \right) \tag{2}$$

Considering clearance of one lane, recall that ***W*** equals 45.72 meters. To maintain the on-to-one ratio, ***N*** equals 179. The author determine that 18", or 0.4572 meters was an accurate figure to use for ***w***. Using these figures, the fractional coverage of one end-to-end pass was calculated as 1.79 meters. Therefore, approximately 26 end-to-end passes are necessary to clear the requisite 50 yard lane through the VSW/SZ. Consequently, the routes of the ALUVs were constructed to include a total of 26 end-to-end passes.

To expedite the time of Janus runs, the author established a maximum movement speed of 45 kilometers per hour. Entries were made in the data base to reflect an ALUV's 23 pound weight (inclusive of its 7 payload pound carrying capacity), its previously mentioned dimensions, its 115 cubic foot volume, its footed movement type, and its ability to operate amphibiously.

D. CHAPTER SUMMARY

This chapter has described the scenarios and amplified their development. Chapter III will present a statistical analysis of the numerical data results obtained from the execution of these scenarios.

III. DATA ANALYSIS

A. OVERVIEW

Statistics is the art of making numerical conjectures about questions of interest. As a stochastic simulation, Janus becomes a useful and economic statistical tool from which to obtain data to begin to answer some of the difficult questions posed by those interested in combat analysis. Ultimately, the author of this thesis seeks to conjecture about the tactical effectiveness of the ALUV as a MCM in the VSW/SZ relative to current Naval Service MCM capabilities for hunting and neutralizing mines in these regions.

This chapter provides a statistical analysis of the data obtained from the Janus scenario runs. Following this overview, a discussion of the run sample size derivation precedes a section that presents a nonparametric statistical test to determine which, if any, MCM is best. These two sections assume that the reader is familiar with probability and statistics. Readers who lack this mathematical experience can skip these two sections without losing an appreciation of the inferences drawn from the data. The concluding section introduces specific measures of effectiveness (MOEs) which are used as bases for analysis of the data. The data displayed in this concluding section has often been summarized to provided succinct appealing graphs. Appendix D contains a more detailed display of the data extracted from Janus. It also includes summary statistics.

B. HOW MANY SCENARIO RUNS?

It is desirable to select a sample size that minimizes the detection of unimportant effects and maximizes the detection of important effects, while retaining the true characteristics of the underlying distribution of the data. The author faced this challenge when determining an appropriate number of scenario runs to simulate.

As mentioned earlier, Janus is a stochastic system that determines the result of actions like detections or minefield crossing events according to the laws of probability and chance. While it is highly unlikely, the interplay of probabilities could possibly generate an occurrence that is unrepresentative of what would actually happen in reality. The rarity of such occurrences probably supersede one in ten thousand Janus runs. But the author, to be conservative, has assumed that they occur more frequently, one in one hundred Janus runs. These runs could be considered failed Janus runs. By characterizing the successful Janus runs as a proportion, the author used statistical methods to obtain the number of runs necessary to fit the criteria delineated in the previous paragraph.

If we assume that failures occur at a rate of one in one hundred, successes occur at a rate of ninety-nine in one hundred. This proportion of success, $\boldsymbol{p}$, represents the probability of a successful run. Consequently, $\boldsymbol{p} = \frac{99}{100} = 0.99$.

As with all experiments, the researcher must determine the precision and confidence level desired of the results. In an effort to keep the number of runs at a reasonable level with minimal sacrifice of precision and confidence, the author set both levels to 95%. Since the

precision level is 95%, the maximum expected error, E, is 5%. From probability and statistics, it is known that a $(1-\alpha)$ confidence interval gives an upper and a lower value between which p can expect to fall $100(1-\alpha)\%$ of the time. Since our confidence level is given as 95%, a decimal representation of α can be obtained. Hence, $(1-\alpha) = 0.95$ implies that $\alpha = 0.05$. The Central Limit Theorem implies that a random sample of the successful runs is approximately standard normal when the sample size is sufficiently large. Using the values of p, E, and α, and the table for the probabilities of a standard normal distribution, the author used Equation 3 [Ref. 18, page 240] to estimate n, the required number of scenario runs:

$$n = \frac{(z_{\alpha/2})^2\, p\,(1-p)}{E^2} \tag{3}$$

$$= \frac{(1.96)^2\; 0.99\;(1-0.99)}{0.05^2}$$

$$= 15.21$$

Rounding 15.21 up to the nearest integer gives a required number of 16 scenario runs to simulate.

C. A NONPARAMETRIC STATISTICAL TEST OF LANDING FORCE KILLS

Very often in practice researchers make decisions about populations (groups of data) on the basis of sample information. In attempting to reach such decisions, it is useful to make assertions (or guesses) about the populations involved. Such assertions, which may or may not be true, are called statistical hypotheses. They are general statements about the probability distribution of the underlying population. In many instances, a researcher formulates a statistical hypothesis for the sole purpose of rejecting it.

If a particular hypothesis is true but the results observed in a random sample differ markedly from the results expected under the hypothesis, then the observed differences are significant and inclination would suggest rejecting the hypothesis. Procedures that enable a researcher to determine whether observed samples differ significantly from the results expected, and thus help the researcher to decide whether to accept or reject the hypothesis, are called tests of hypotheses or tests of significance. Most tests of hypotheses and significance (or decision rules) require various assumptions about the distribution of the population from which the samples were drawn. But situations arise in practice in which such assumptions may not be justified or in which there is doubt they apply. Consequently, statisticians have devised various tests and methods that are independent of population distributions and associated parameters. These are called nonparametric tests.

Since the observed samples from the scenarios have unknown distributions, the author employs the Mann-Whitney U Test, a nonparametric test which can be used to

evaluate two independent samples to determine which population mean exceeds the other. This test is conducted by ranking the observed values and analyzing the ranks instead of the original data. In an interrogative sense the author seeks three answers:

1. Is Bull Breaching a more effective MCM than Traditional Breaching?
2. Is Bull Breaching a more effective MCM than ALUV Breaching?
3. Is Traditional Breaching a more effective MCM than ALUV Breaching?

Translating to statistical hypotheses gives a null hypothesis:

H_O: Population mean of MCM 1 = Population mean of MCM 2

The null hypothesis is tested against three distinct alternative hypotheses, using LF kills per scenario as a measure:

H_{A1}: Population mean of Bull Breaching (MCM 1) > Population mean of Traditional Breaching (MCM 2)

H_{A2}: Population mean of Bull Breaching (MCM 1) > Population mean of ALUV Breaching (MCM 2)

H_{A3}: Population mean of Traditional Breaching (MCM 1) > Population mean of ALUV Breaching (MCM 2)

Recall now that 32 landing craft comprise the LF, 23 AAVs and 9 LCACs. A cursory look at the data via Figure 8 suggests that the null hypothesis will indeed be rejected in each of the three cases.

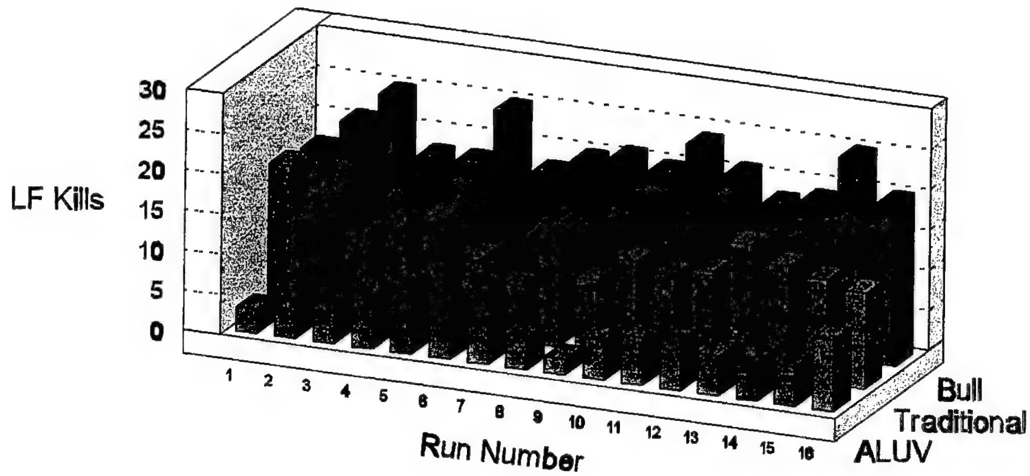

Figure 8. LF Kills by Scenario (by run)

Now we examine the test to see if it supports the assertion that the null hypothesis will be rejected. The null hypothesis will be rejected at the significance level $\alpha = 0.05$ only if the observed value of U is less than or equal to the critical value of 83 (obtained from the Table of Critical Values of Mann-Whitney U in Reference 19).

1. H_0 verses H_{A1}

Table 1 contains the results of the Mann-Whitney U Test for this case. The author used the ranked sums and the sample sizes to calculate an observed U statistic of 3. Since

Mann-Whitney U Test

Level	Sample Size	Ranked Sum	Ranked Mean LF Kills
Bull	16	389	24.3125
Traditional	16	139	8.6875
Observed U	Prob > U (p-value)		
3	< 0.0001		

Table 1. Mann-Whitney U Test of H_O verses H_{A1}

3 is much less than 83 and the ranked mean LF kills of the Bull Breaching Scenario exceed that of the Traditional Scenario, H_O is rejected and H_{A1} is assumed. Note the p-value in the table. A p-value is the probability of being wrong if an effect is declared non-null. This small p-value indicates that the author can conclude with reasonable certainty that, relative to LF Kills, Traditional Breaching is a more effective MCM than Bull Breaching.

2. **H_O verses H_{A2}**

Table 2 contains the results of the Mann-Whitney U Test for this case. The author used the ranked sums and the sample sizes to calculate an observed U statistic of zero. Incidentally, a U Statistic of zero indicates that no rank in the lower ranking group exceeds any ranks in the higher ranking group. Figure 1 justifies this statement. Since zero is much less than 83 and the ranked mean LF kills of the Bull Breaching Scenario exceed that of the ALUV Scenario, H_O is rejected and H_{A2} is assumed. Note the p-value in the table. This small

p-value indicates that the author can conclude with reasonable certainty that, relative to LF Kills, ALUV Breaching is a more effective MCM than Bull Breaching.

Mann-Whitney U Test

Level	Sample Size	Ranked Sum	Ranked Mean LF Kills
ALUV	16	136	8.5
Bull	16	392	24.5
Observed U	Prob > U (p-value)		
0	< 0.0001		

Table 2. Mann-Whitney U Test of H_0 verses H_{A2}

3. H_0 verses H_{A3}

Table 3 contains the results of the Mann-Whitney U Test for this case. The author used the ranked sums and the sample sizes to calculate an observed U statistic of 7.5. Since 7.5 is much less than 83 and the ranked mean LF kills of the Traditional Scenario exceed that

Mann-Whitney U Test

Level	Sample Size	Ranked Sum	Ranked Mean LF Kills
ALUV	16	143.5	8.9688
Traditional	16	384.5	24.0313
Observed U	Prob > U (p-value)		
7.5	< 0.0001		

Table 3. Mann-Whitney U Test of H_0 verses H_{A3}

of the ALUV Scenario, H_O is rejected and H_{A3} is assumed. Note the p-value in the table. This small p-value indicates that the author can conclude with reasonable certainty that, relative to LF Kills, ALUV Breaching is a more effective MCM than Traditional Breaching.

D. MEASURES OF EFFECTIVENESS (MOEs)

1. Landing Force Kills

Recall again that 32 landing craft comprise the LF, 23 AAVs and 9 LCACs. Figure 9 clearly displays a comparison of average landing force (LF) kills by mine type and by

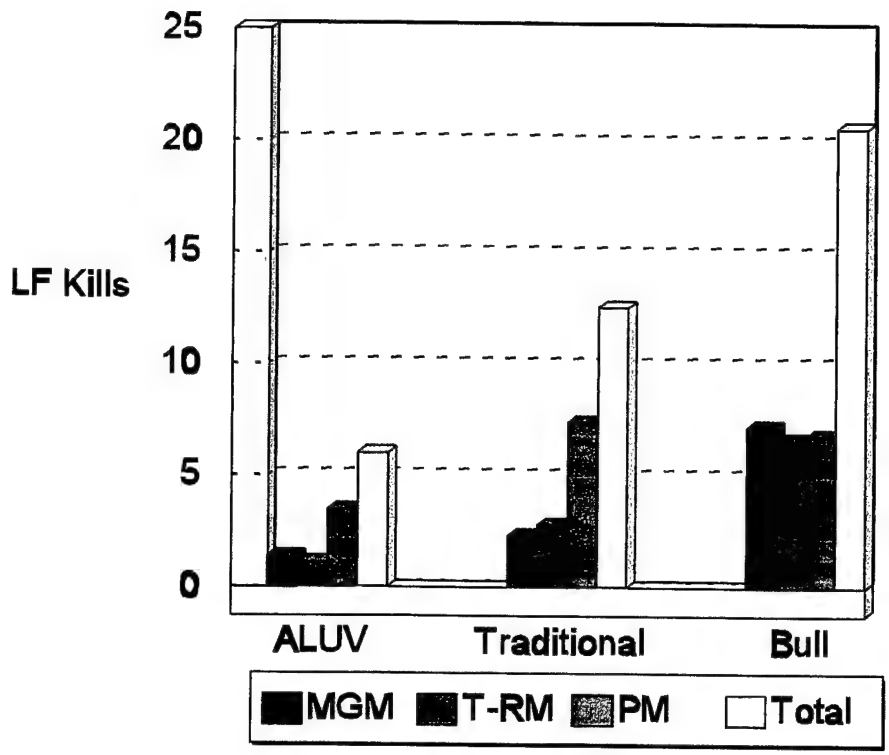

Figure 9. Average LF Kills by Mine Type (by scenario)

scenario. The figure reveals that PMs had the greatest effect on the LF in the ALUV Scenario, although not by much. MGMs, T-RMs, and PMs respectively accounted for 1.37, 1.13, and 3.5 of the total average of 6 LF kills in the ALUV Scenario. PMs also had the greatest effect on the LF in the Traditional Scenario, this time by a larger margin. MGMs, T-RMs, and PMs respectively accounted for 2.3, 2.8, and 7.45 of the total average of 12.55 LF kills in the Traditional Scenario. The Bull Breaching Scenario had a fairly even dispersion of kills between the three mine types. MGMs, T-RMs, and PMs respectively accounted for 7.2, 6.6, and 6.8 of the total average of 20.6 LF kills in the Bull Breaching Scenario.

When comparing the three scenarios, it becomes evident that the total average number of LF kills in the Bull Breaching Scenario exceed the total average number of LF kills in the Traditional Scenario. And the total average number of LF kills in the Traditional Scenario exceed the total average number of LF kills in the ALUV Scenario. Furthermore, the same result holds when comparing the number of LF kills induced by each mine type, with one exception. PM kills when comparing the Bull Breaching Scenario and the Traditional Scenario provides the exception. One may wonder why the number of PM kills is approximately equal in these two scenarios. In three of the sixteen Traditional Scenario runs, the MCM assets did not make it to the SZ to clear a lane for the LF. These assets were killed by MGMs in the VSW. Additionally, when the SZ MCMs of the Traditional Scenario did make it to the SZ to perform their mission, many were rendered ineffective at the hands of T-RMs. Resultingly, these assets never cleared a lane through PMs. These results indicate, as in the real life case, that the SZ still poses a formidable challenge for traditional MCM

assets. This comparative analysis suggests that ALUVs are the best MCM, followed by traditional MCMs.

2. Cost Analysis

Operational demands on today's military forces have continued to increase while financial resources allocated to the Department of Defense have steadily declined. Military fiscal planners anticipate that these trends will continue in the near future. Consequently, military personnel responsible for procuring weapons and systems have difficult choices to make. Cost is one significant factor that is considered in the procurement process.

By considering the actual cost of each AAV and LCAC in the LF and the difference in the LF kill rates between scenarios, the author generated data which depicts the approximate fiscal savings (Figure 10) when employing one MCM vice another. These dollar figures include the total cost of landing craft losses incurred, but omit the operational costs incurred from conducting each MCM technique. An analysis of the operational costs is beyond the scope of this thesis. Realize also that the actual fiscal savings may differ when the size and composition of the LF change. But the general conclusion is that there is a fiscal savings when employing: Traditional MCMs vice Bull Breaching, ALUV MCMs vice Bull Breaching, or ALUV MCMs vice Traditional MCMs.

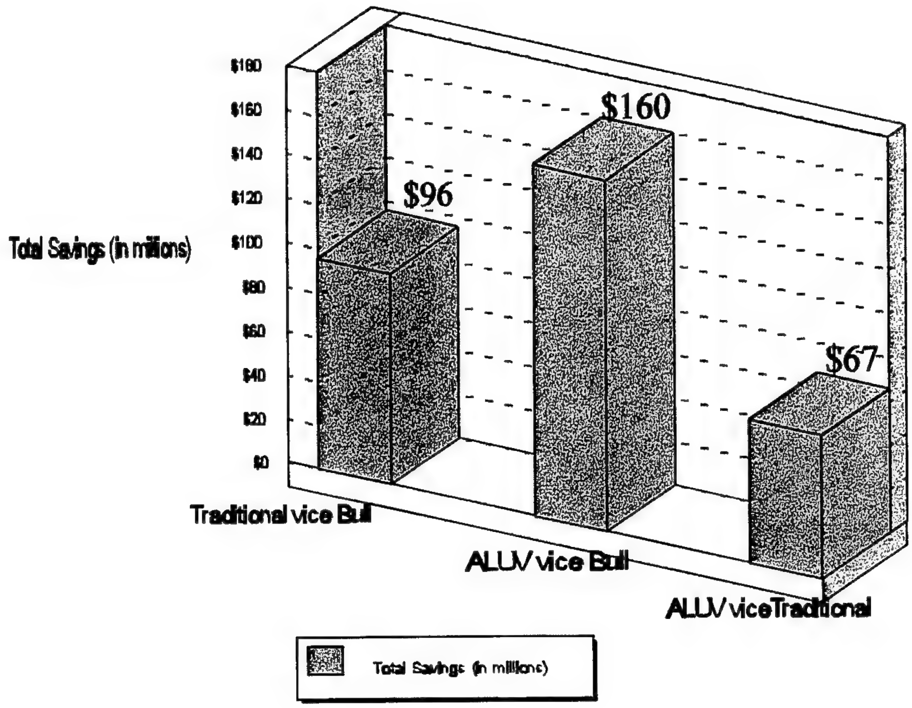

Figure 10. Fiscal Savings (in millions) when Employing one MCM vice Another (Includes Total Cost of Landing Craft Losses, Not Operational Costs)

One LCAC costs twenty-seven million dollars [Ref. 20]. One AAV costs 2.5 million dollars [Ref. 21]. The Janus data indicates that on average the Bull Breaching, Traditional, and ALUV scenarios respectively sustained 14.5, 9.19, and 4.63 AAV kills. The Bull Breaching, Traditional, and ALUV scenarios also respectively sustained 6.125, 3.375, and 1.375 LCAC kills. By using these numbers to take the difference in AAV kills between

scenarios and the difference in LCAC kills between scenarios, the results in Table 4 were obtained. Note that any fractional portion was rounded to the next higher integer. The author used the numbers contained in Table 4 and the respective costs of AAVs and LCACs to produce Figure 10.

Number Of Landing Craft Saved when Employing Differing MCMs

Landing Craft	Traditional vice Bull	ALUV vice Bull	ALUV vice Traditional
AAV	6	10	5
LCAC	3	5	2

Table 4. Number of Landing Craft Saved when Employing one MCM vice Another

This cost analysis suggests that ALUVs are the most cost effective MCM relative to costs incurred from landing craft losses. Furthermore, the developers of the ALUV project that the cost of each ALUV will be less than $1,000, a dollar figure that is significantly less than the 27 million dollar cost of just one LCAC configured for MCMs.

3. Combat Power Ashore

Figure 11 diagrams the percentage of combat power to reach the shore by scenario. This measure provides another way of characterizing the relative effectiveness of each MCM.

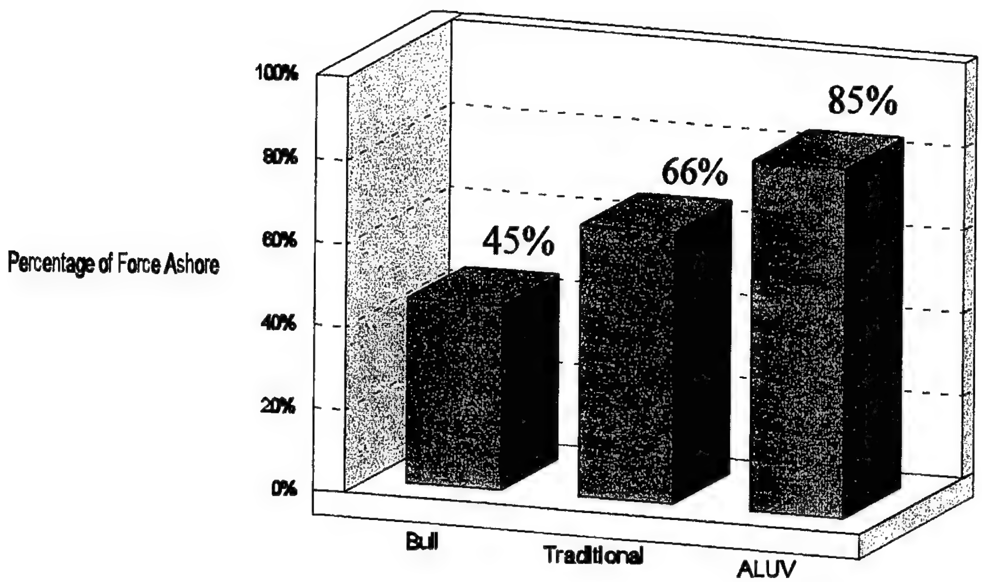

Figure 11. Average Percentage of Combat Power Ashore by Scenario

To develop this diagram, the author calculated the mean average of the number of surviving landing craft for each scenario. Note that each LCAC had two opportunities to be killed, inbound or outbound. If the LCAC survived its inbound journey, it was able to offload its contents at the landing site and thus is included in the calculations contained in this diagram. The outbound fate of LCACs provides no information for these calculations. AAVs

transit the mined landing craft lanes only once, so they project combat power ashore only if they survive their single transit to the shore.

The results of this MOE suggest that ALUVs are approximately 20% more effective than the traditional method of clearing a mined landing lane. The fact that only 45% of the force reached the shore in the Bull Breaching Scenario emphasizes the urgent need for effective MCMs in the VSW/SZ.

4. Mines Neutralized in the ALUV Scenario

On average, approximately 341 of the possible 358 mines were neutralized in the ALUV Scenario. In other words, the ALUVs cleared approximately 95% of the mines present in the minefields. Recall that a one-to-one ALUV-to-mine ratio was used in this experiment. If this ratio is increased, the clearance rate of the ALUVs will probably increase also.

E. CHAPTER SUMMARY

This chapter has provided a detailed analysis of the data extracted from Janus at the completion of all simulation runs. The following chapter will summarize the results of this study and provide recommendations regarding the ALUV as a MCM in the VSW/SZ.

IV. CONCLUSION

A. SUMMARY

In purpose this thesis has sought to evaluate the tactical effectiveness of the Autonomous Legged Underwater Vehicle (ALUV) as a mine countermeasure (MCM) in the very shallow water and the surf zone relative to current Naval Service capabilities for hunting and neutralizing mines in these regions. With the aid of the Janus combat simulation computer model, the author developed three scenarios which focused on highlighting the differences in effectiveness of bulling a landing force through a mined landing zone, landing a force through a mined landing zone after employing current or "traditional" MCM methods, and landing a force through a mined landing zone after employing ALUVs as a MCM. The scenarios were identical, other than the MCM method employed. The traditional MCMs comprised four MH-53s towing Mk-105 hydrofoils to counter the very shallow water mine threat and two LCACs with twelve line-charges mounted on each to counter the surf zone threat. The Kernel Blitz 95 exercise guided the development of the scenarios and provided the composition of the landing force, 23 Amphibious Assault Vehicles and 9 Landing Craft Air Cushioned. To concentrate the modeling effort on the analysis of MCMs, the author assumed that the amphibious landing force encounter no opposing enemy fire.

Using statistical methods, the author determined that sixteen runs of each scenario was sufficient to glean the information required of this research with minimal sacrifice of precision and confidence. A nonparametric statistical method was used to compare the three

scenarios with regard to landing force kill data. This method sought answers to these three questions:

1. Is Bull Breaching a more effective MCM than Traditional Breaching?
2. Is Bull Breaching a more effective MCM than ALUV Breaching?
3. Is Traditional Breaching a more effective MCM than ALUV Breaching?

The answer to each of these questions was no.

The author then focused on four measures of effectiveness: landing force kills by scenario and by mine type, total cost of landing craft losses, combat power ashore, and percentage of mines neutralized in the ALUV Scenario. Landing force kills by scenario revealed that the ALUV Scenario suffered an average of six kills, while the Traditional and Bull Breaching Scenarios respectively suffered an average of approximately 13 and 21 kills. Pressure mines proved most lethal in the ALUV and Traditional Scenarios, while the Bull Breaching Scenario saw a fairly even distribution of kills among the three mine types: pressure mines, tilt-rod mines, and magnetic influence mines. The cost analysis suggested that there is a fiscal savings when employing: Traditional MCMs vice Bull Breaching, ALUV MCMs vice Bull Breaching, or ALUV MCMs vice Traditional MCMs. The combat power ashore study showed that on average 85% of the ALUV Scenario landing force safely made it ashore, while the average percentage of combat power ashore in the Traditional and Bull Breaching Scenarios was 66% and 45%, respectively. Finally, with a one-to-one

ALUV-to-mine ratio, the ALUVs cleared an average of 95% of the mines present in the minefields.

B. RECOMMENDATION

This study indicates that ALUVs, as modeled, counter mines more effectively than current countermeasures employed in the VSW/SZ. This conclusion is drawn with the understanding that modeling and simulation is a tool that has strenghts and limitations. Its limitations lie in its inability to re-create actual physical conditions and the "fog" of war; its is not a panacea. It is, however, a valuable tool useful for gaining insight into many of the questions that puzzle those interested or involved in combat analysis. With these thoughts in mind, the author feels confident that the Naval Service should vigorously explore ALUVs as a possible solution to the VSW/SZ mine countermeasure problem.

APPENDIX A. LIST OF ACRONYMS AND ABBREVIATIONS

A

AAV	amphibious assault vehicle
ALUV	autonomous legged underwater vehicles
AOA	amphibious objective area

C

CLA	craft landing area
CLZ	craft landing zone

E

E	error, expected maximum

F

f	fraction or ratio of ALUVs to mines

H

H_{A1}	hypothesis, alternative
H_{A2}	hypothesis, alternative
H_{A3}	hypothesis, alternative
HAND EMP	hand emplaced Janus minefield
H_O	hypothesis, null
HTA	helicopter transport area

I

ITA	inner transport area

L

LCAC	landing craft air cushioned
LCU	landing craft utility
LF	landing force
LOD	line of departure

M

M	mines, expected number
M-58	mine clearing line charge
MCM	mine countermeasure
MDA	mine danger area
MECH-1	minefield, Janus ground vehicle emplaced
MECH-2	minefield, Janus helicopter emplaced
MGM	magnetic influence mine
Mk 105	magnetic sweep gear
MOE	measure of effectiveness

N

n	number of scenario runs
N	number of ALUVs
NEF	Naval Expeditionary Force

O

OMFTS	operational maneuver from the sea
OTA	outer transport area
OTH	over-the-horizon

P

p	proportion of success
PM	pressure mine

R

r	radius, ALUV separation distance

S

SEAL	sea-air-land
SW	shallow water
SZ	surf zone

T

T-RM	tilt-rod mine

V

VSW	very shallow water

W

w	width, ALUV search
W	width, landing lane

APPENDIX B. JANUS SCENARIO IMAGES

This appendix contains selected images captured from actual Janus scenario runs. The images are arranged in chronological order, with general setup images presented first, followed by Bull Breaching Scenario images, Traditional Scenario images, and finally ALUV Scenario images. A brief explanation of each image is included below.

GENERAL SCENARIO IMAGES

Figure B1. Panoramic View of Amphibious Objective Area off the Coast of Red Beach

Figure B2. Close-up View of Mine Danger Area (MDA)

Figure B3. Red Force Helicopter Laying Pressure Mines in the SZ

Figure B4. AAV Task Forces in the ITA with Routes Shown

Figure B5. LCAC Task Force Approaching the Ingress Lane of the Mine Danger Area. The Egress Lane is Clearly Displayed.

BULL SCENARIO IMAGES

Figure B6. Overview of Landing Force Prior to the Amphibious Assault

Figure B7. LCACs Approaching the Mine Danger Area After 15 of 23 AAV Kills

Figure B8. Two LCACs Return to the OTA After 7 of 9 LCAC Kills

TRADITIONAL SCENARIO IMAGES

Figure B9. Overview of Landing Force Prior to the Amphibious Assault. Note the MH-53s in the HTA and the Two LCACs with Mounted Line-Charges in the ITA.

ALUV SCENARIO IMAGES

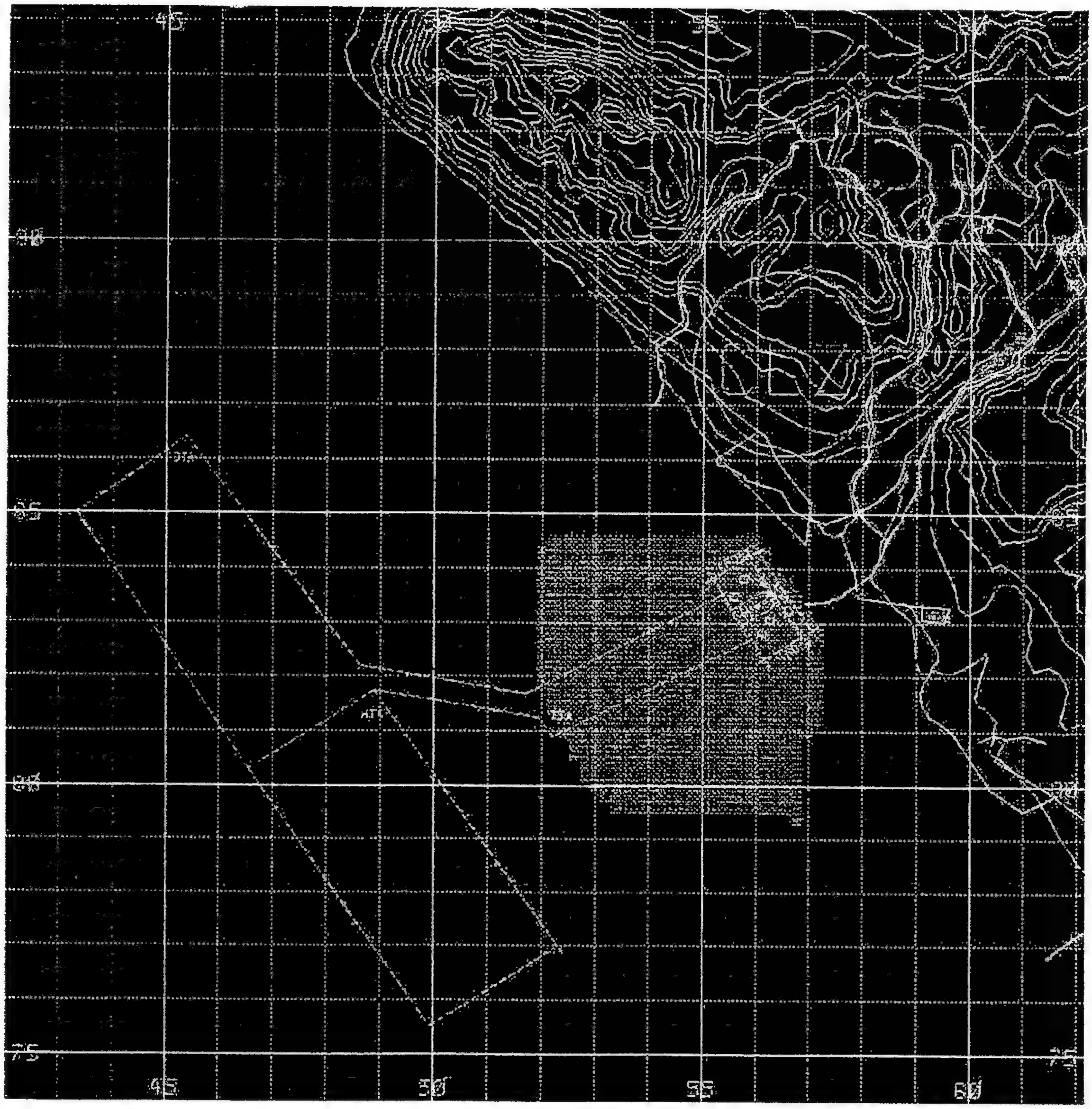

Figure B1. Panoramic View of Amphibious Objective Area off the Coast of Red Beach

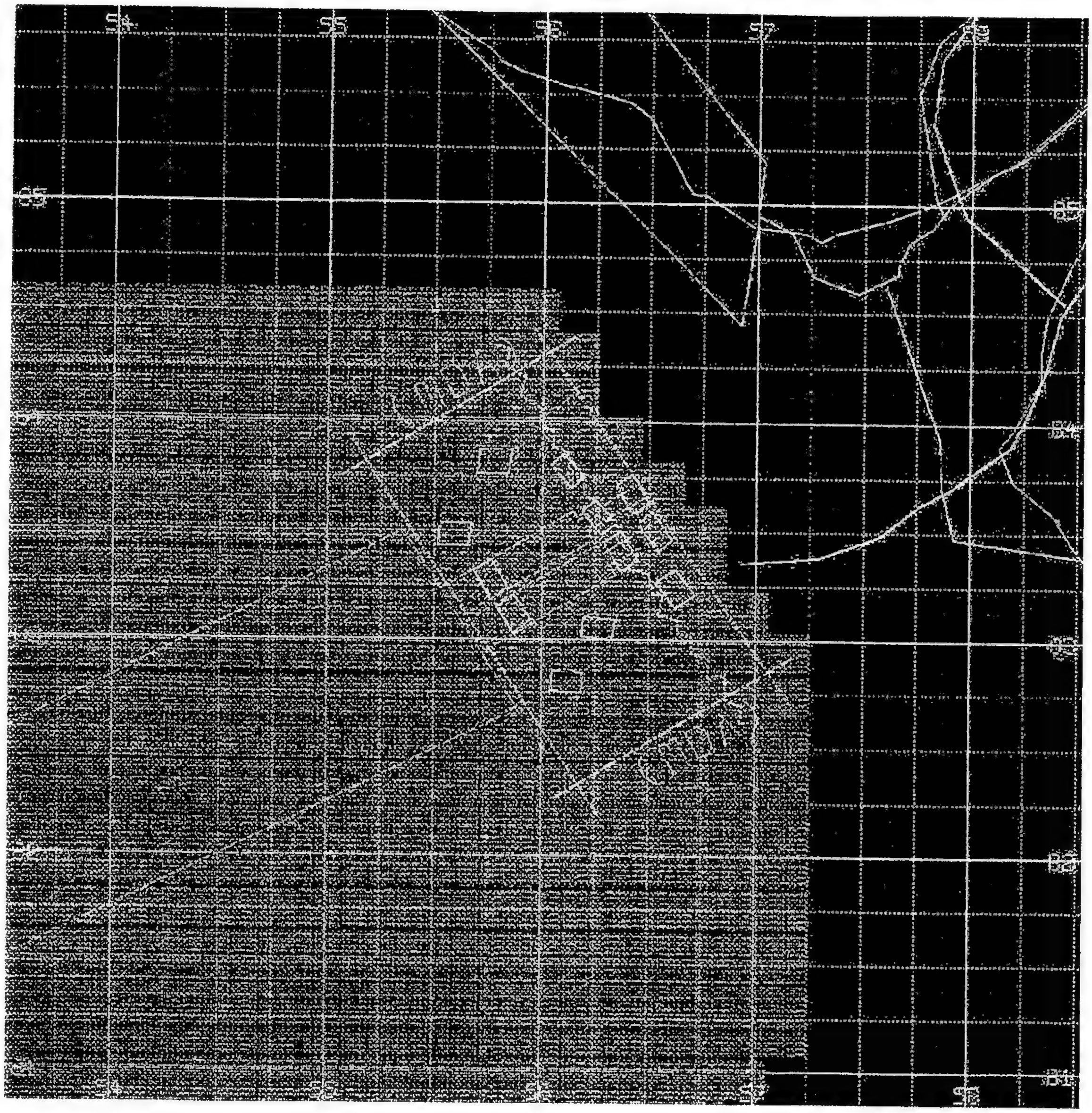

Figure B2. Close-up View of Mine Danger Area (MDA)

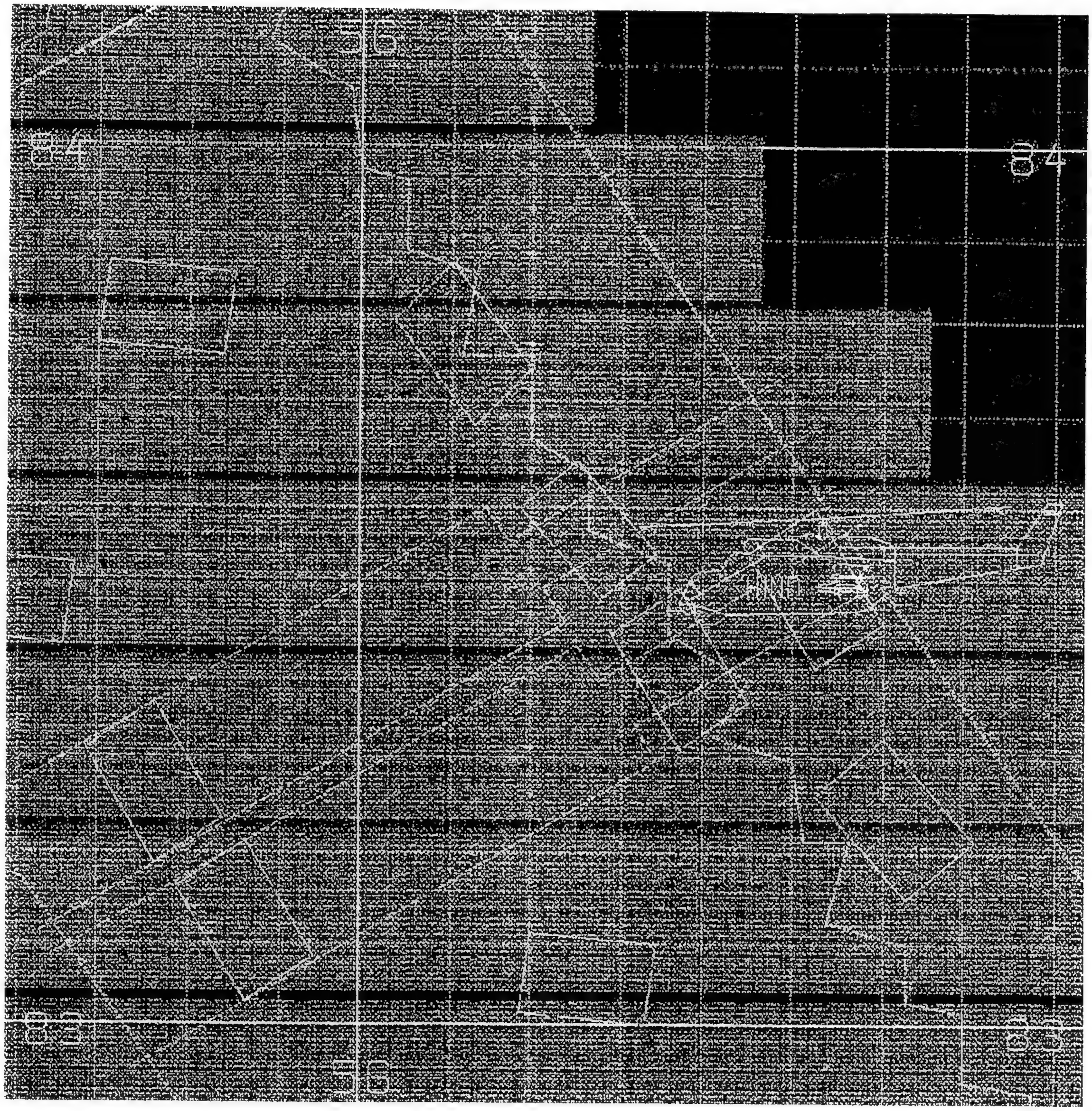

Figure B3. Red Force Helicopter Laying Pressure Mines in the SZ

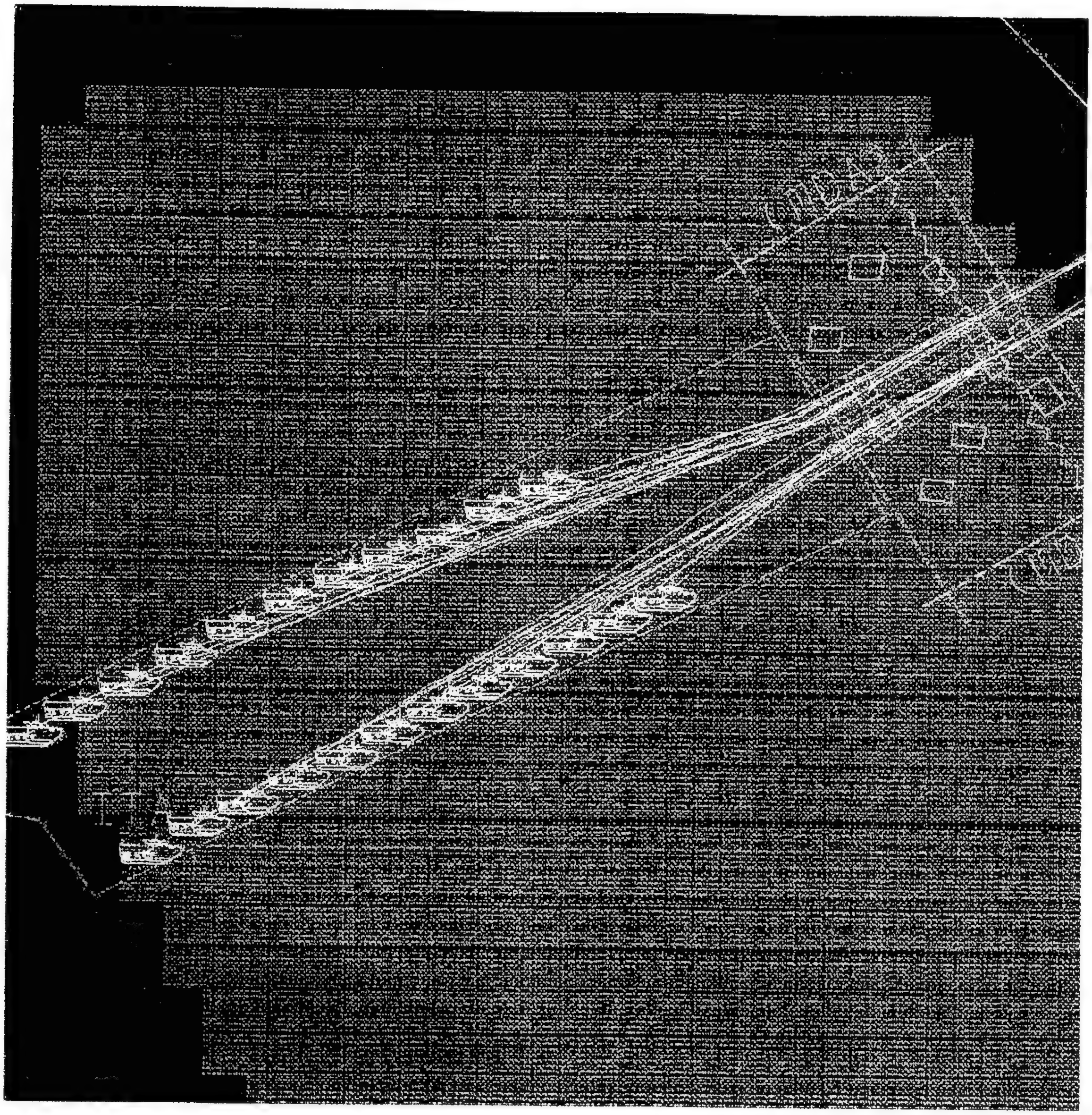

Figure B4. AAV Task Forces in the ITA with Routes Shown

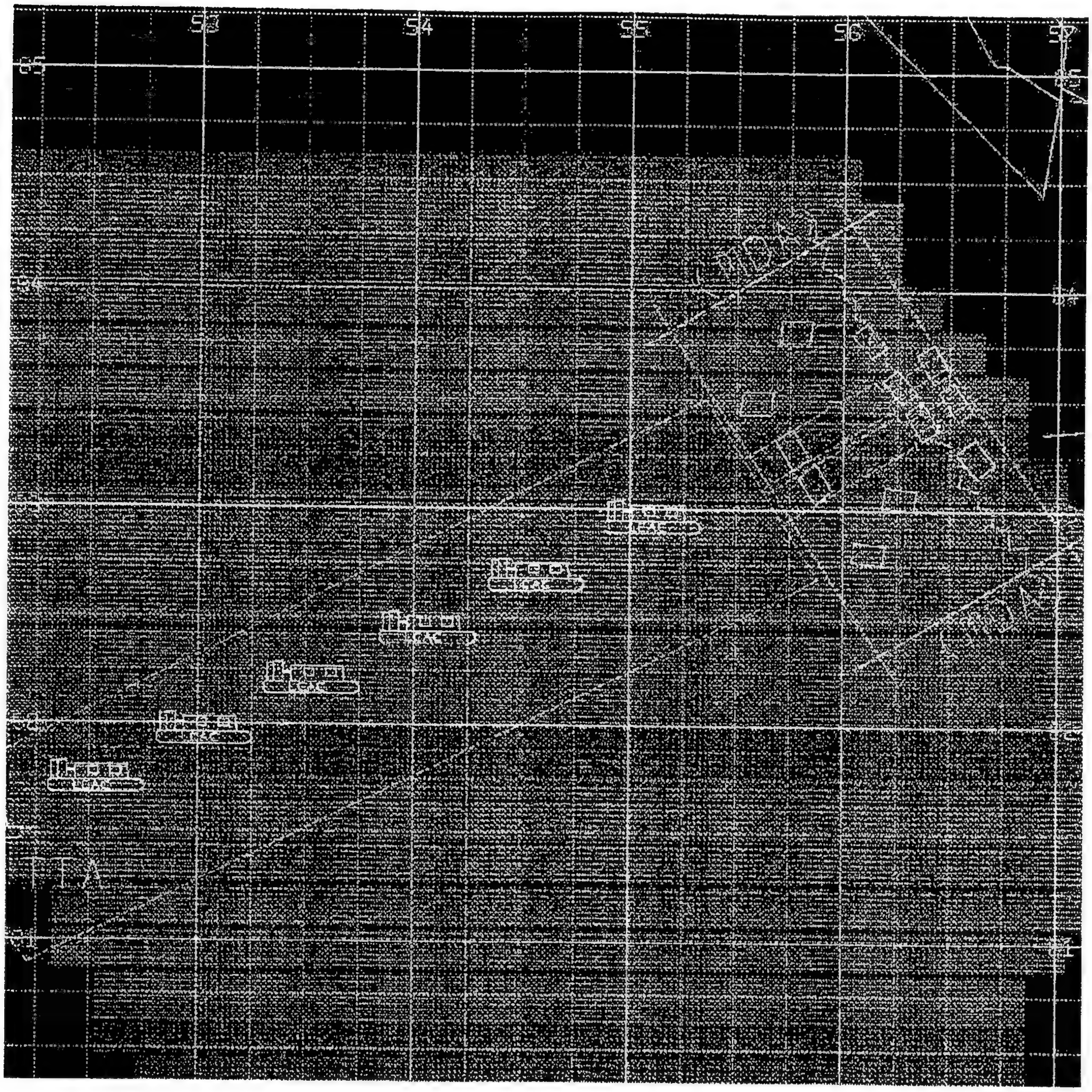

Figure B5. LCAC Task Force Approaching the Ingress Lane of the Mine Danger Area. The Egress Lane is Clearly Displayed.

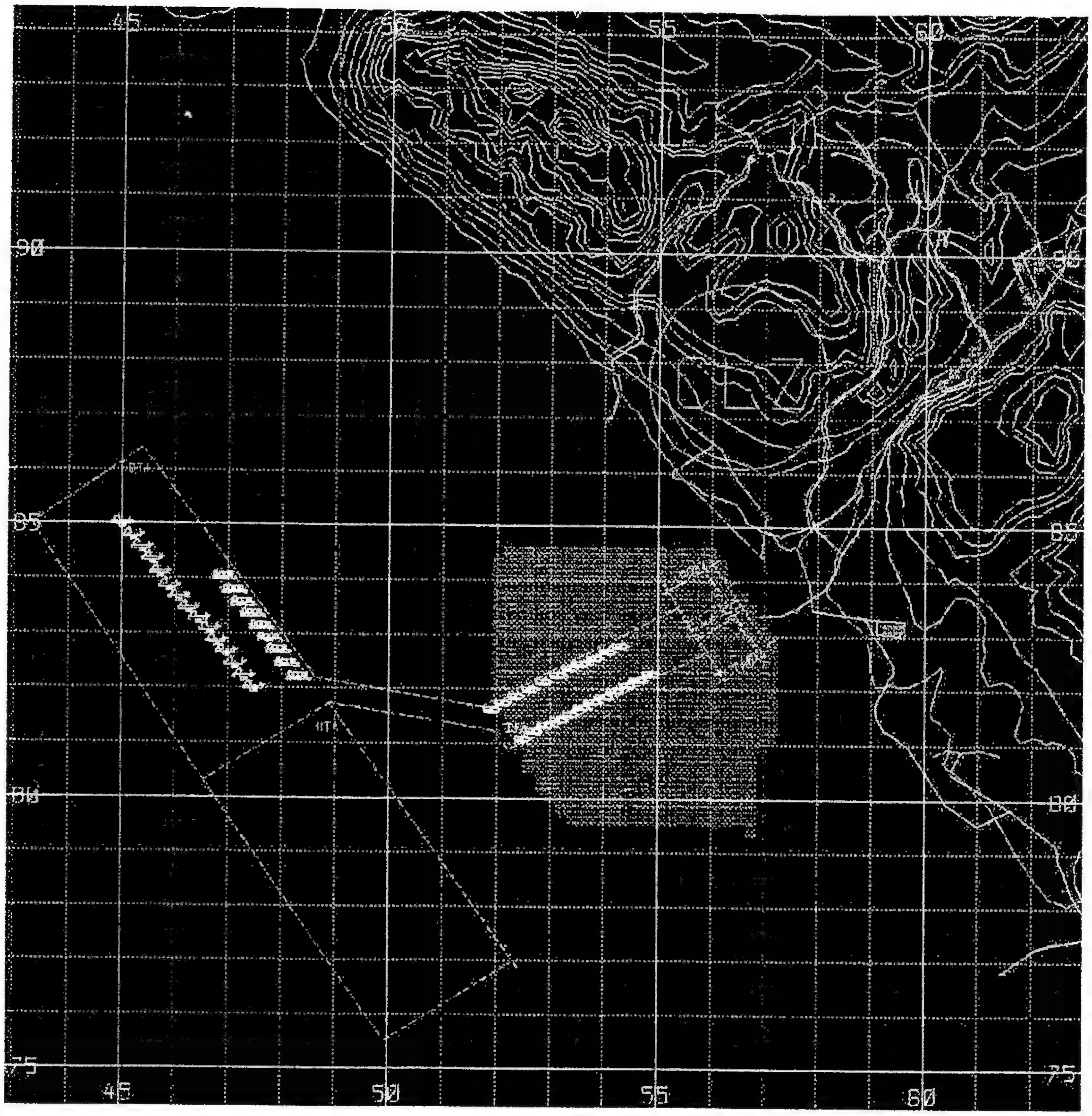

Figure B6. Overview of Landing Force Prior to the Amphibious Assault

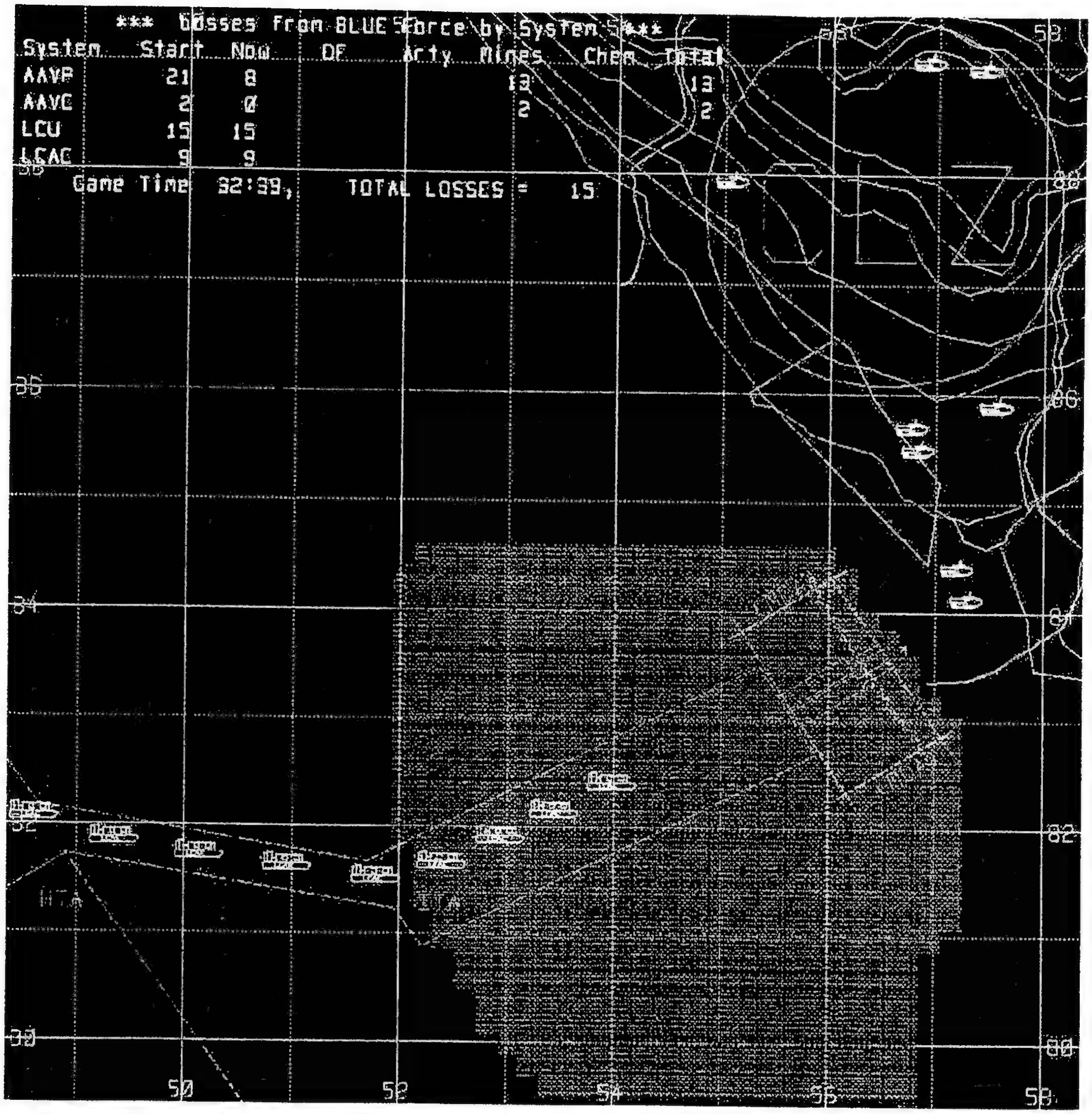

Figure B7. LCACs Approaching the Mine Danger Area After 15 of 23 AAV Kills

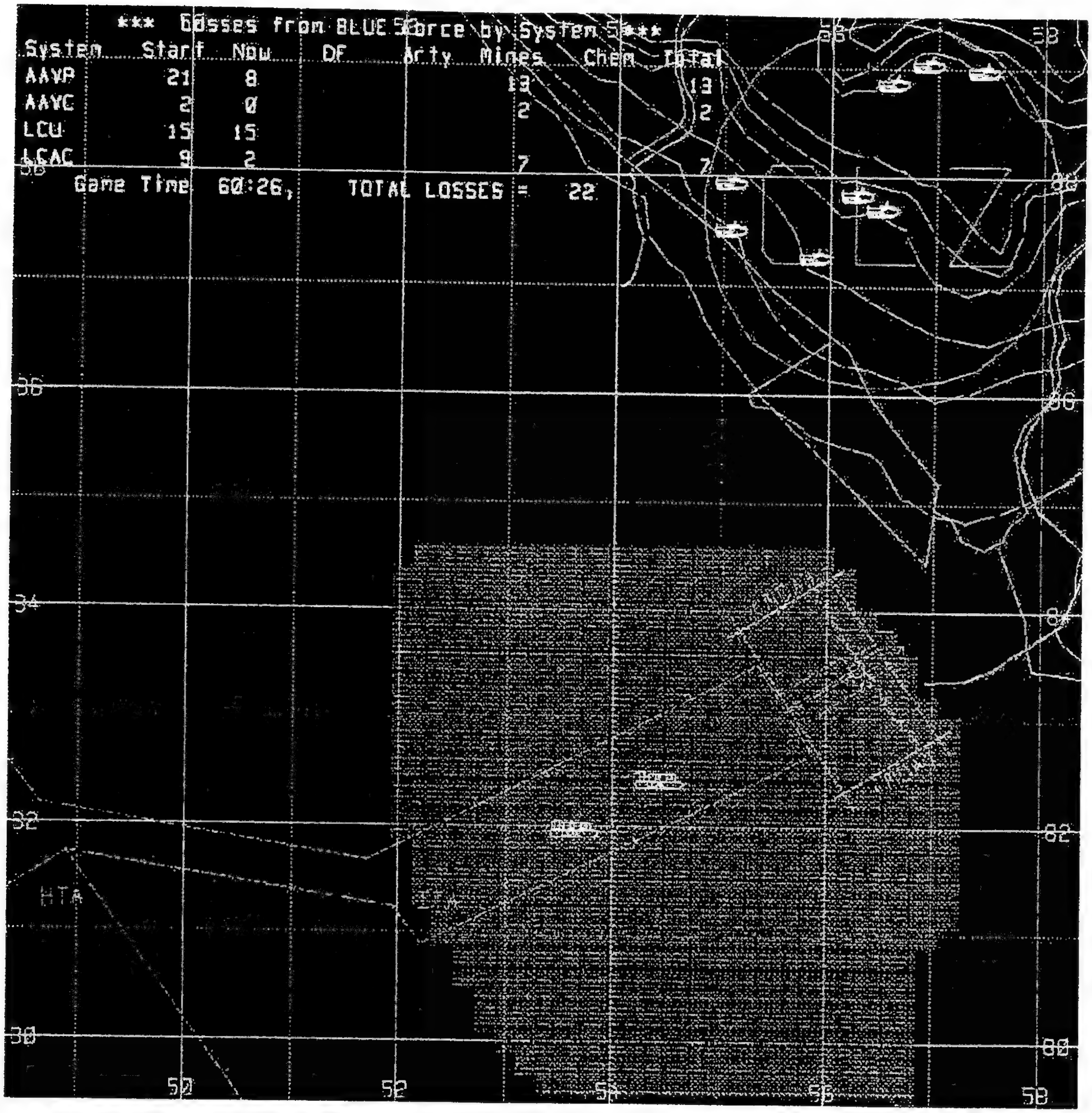

Figure B8. Two LCACs Return to the OTA After 7 of 9 LCAC Kills

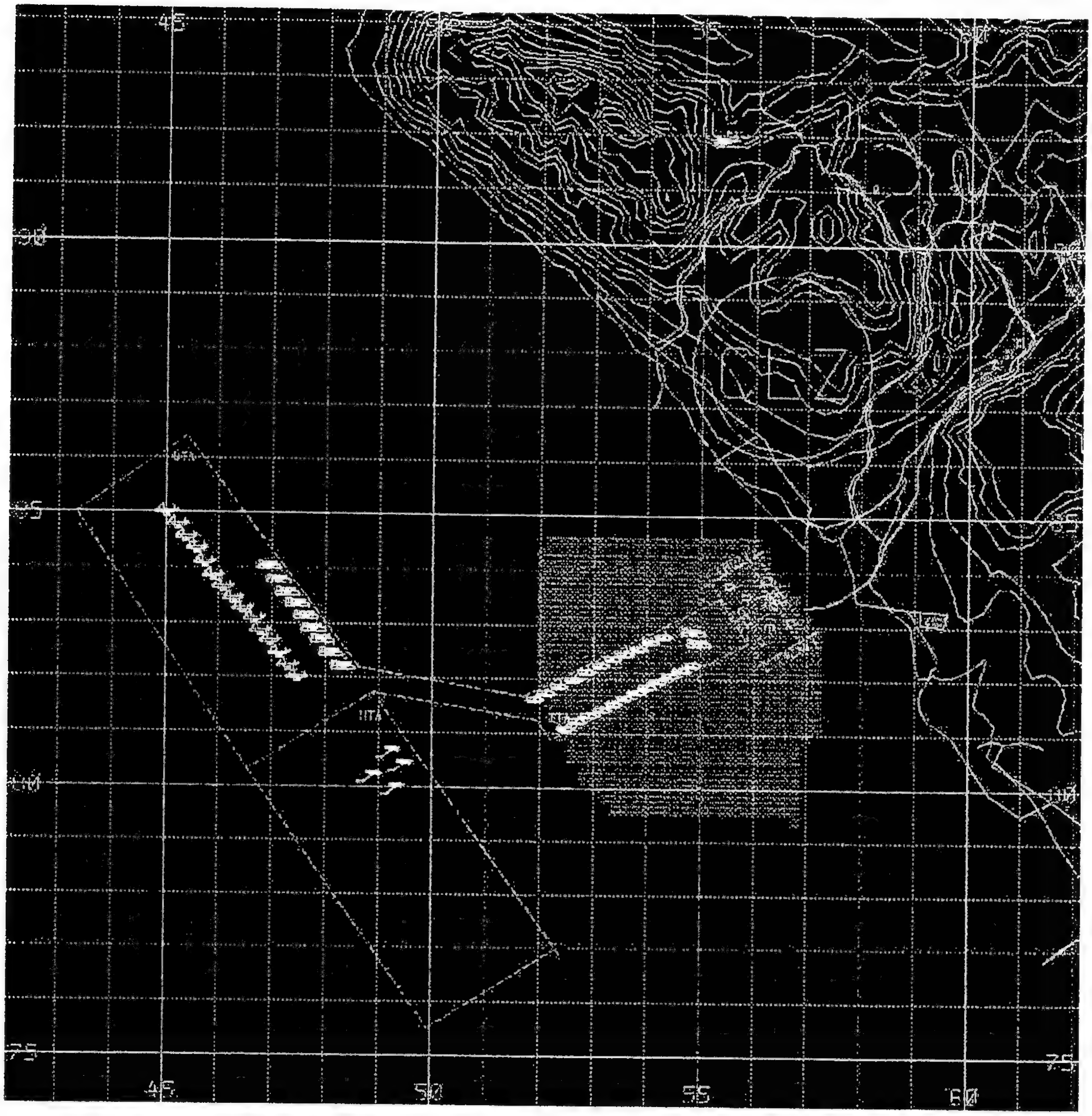

Figure B9. Overview of Landing Force Prior to the Amphibious Assault. Note the MH-53s in the HTA and the Two LCACs with Mounted Line-Charges in the ITA.

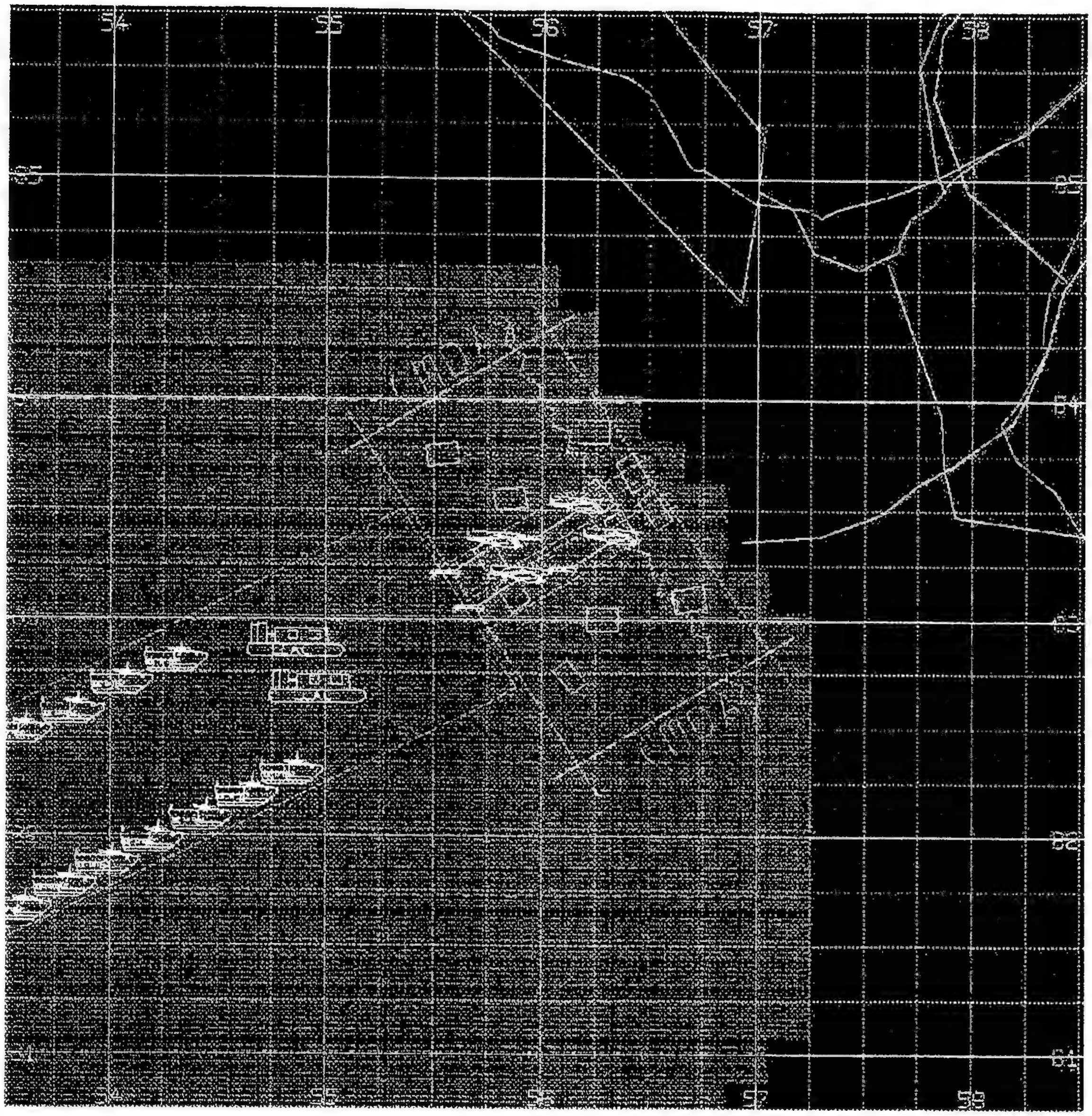

Figure B10. Four MH-53 with Mk-105 Magnetic Sweep Gear Clearing a Lane in the VSW

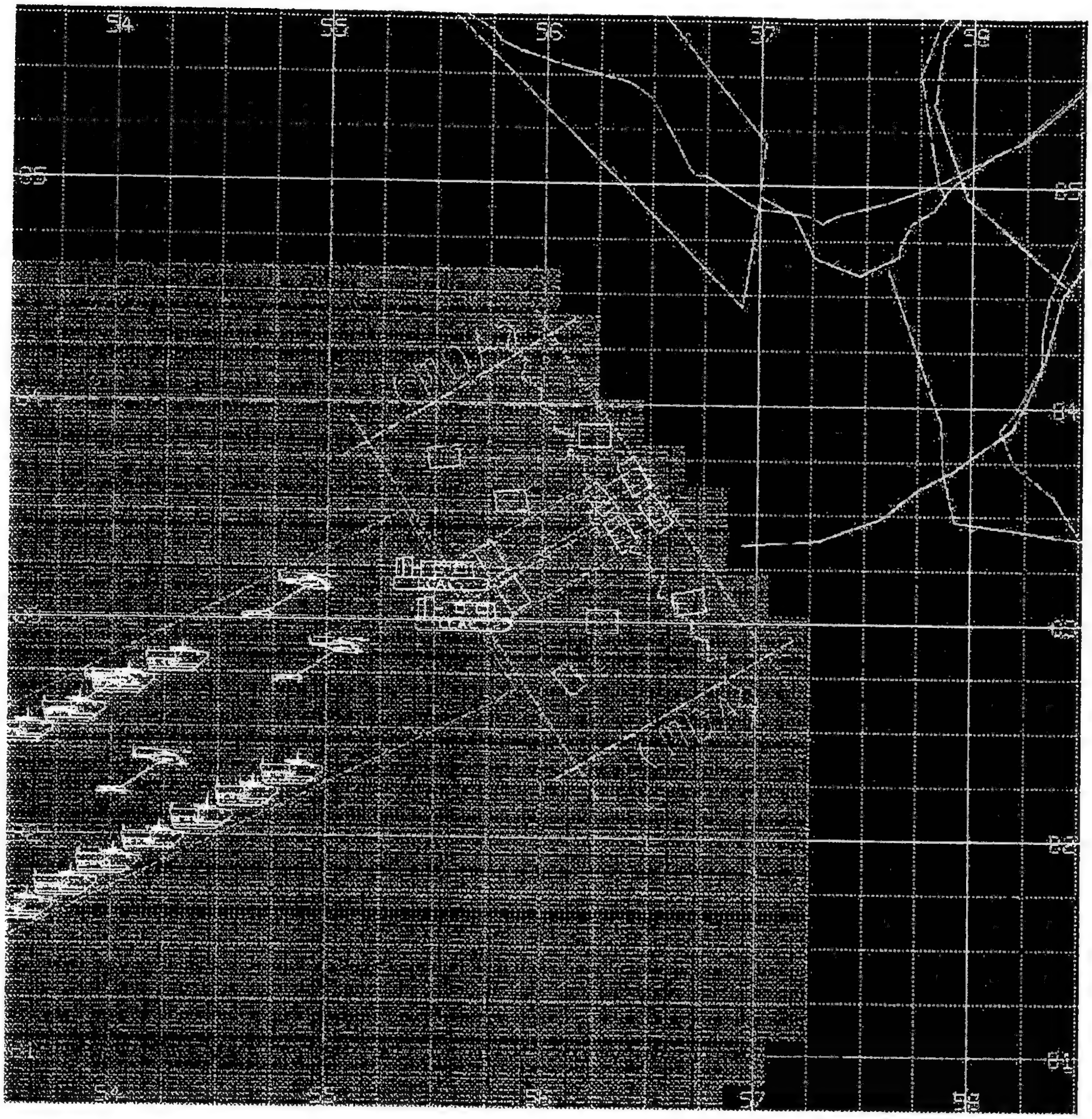

Figure B11. Two LCACs with Mounted Line-Charges Approach the VSW as the MH-53s Return to the HTA

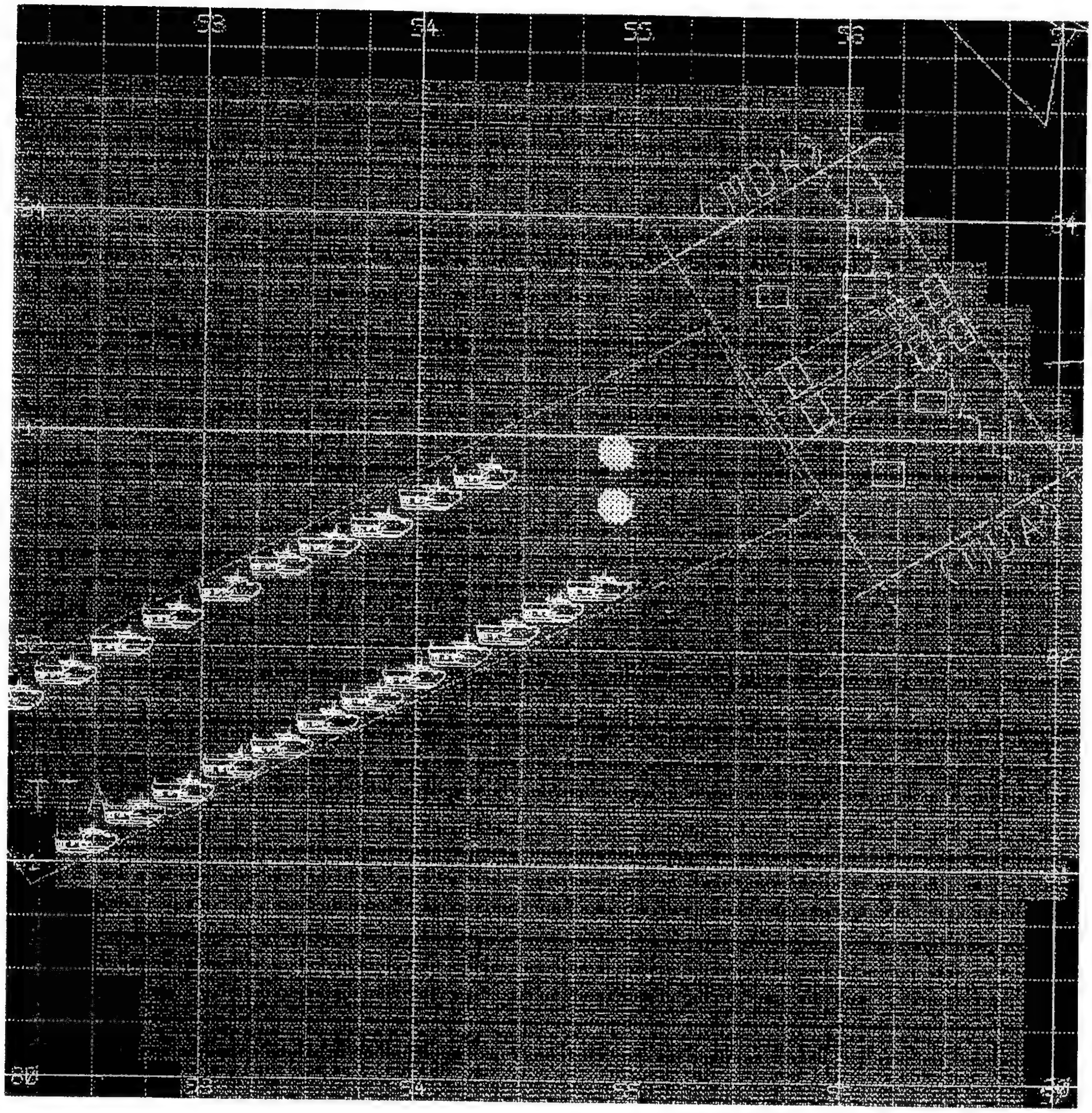

Figure B12. 358 ALUVs in the ITA Prior to Clearing Operations

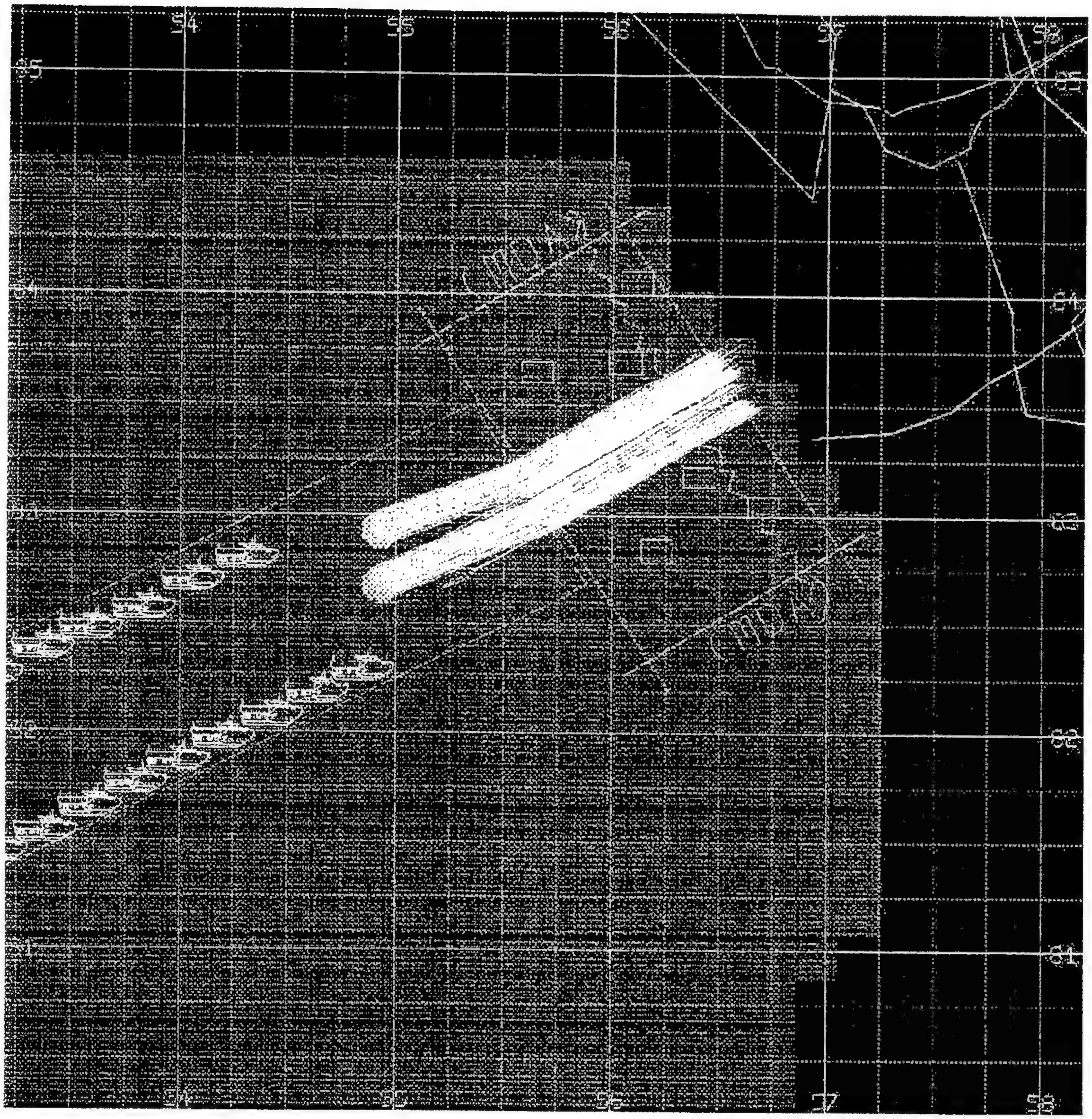

Figure B13. 358 ALUVs in the ITA Prior to Clearing Operations with Routes Shown

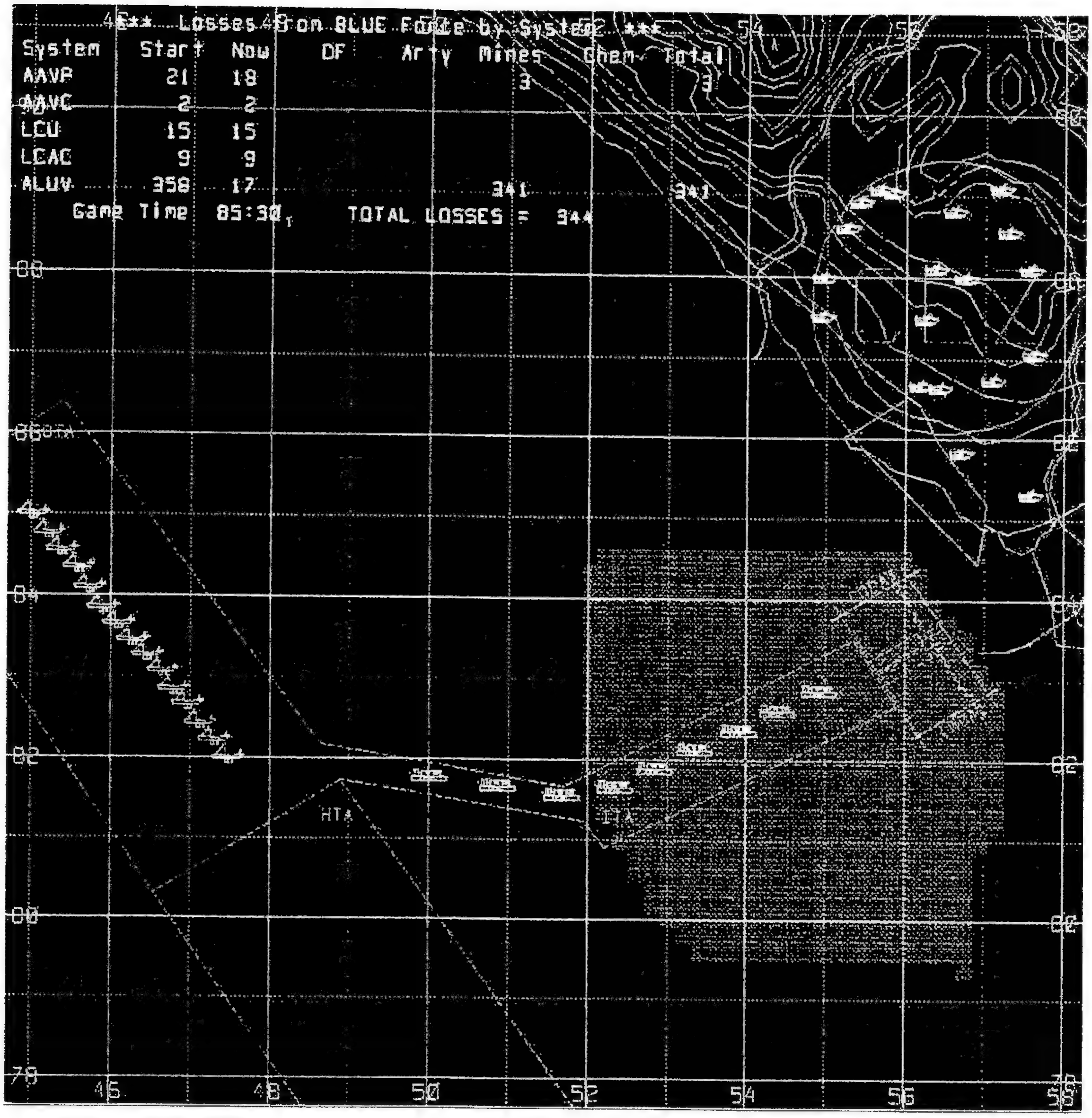

Figure B14. LCACs Approaching the Mine Danger Area After Only 3 of 23 AAV Kills and 95% ALUV Clearance

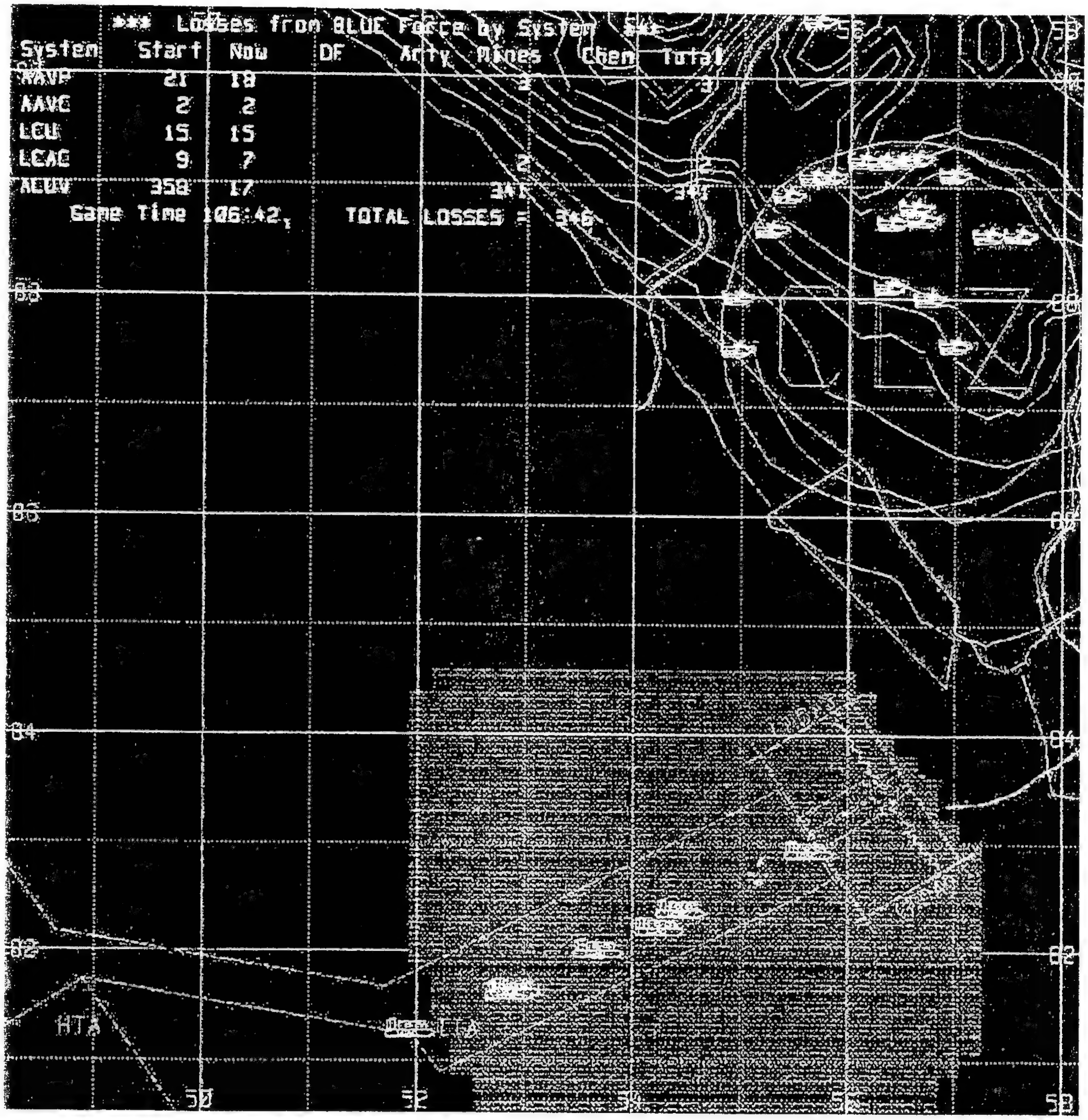

Figure B15. Two LCACs Return to the OTA After Only 2 of 9 LCAC Kills

APPENDIX C. MODELING SYSTEM PROBABILITIES

This appendix contains information on the reliability and survivability probabilities of each breaching asset, the landing craft mine activation and kill probabilities, and the dud probabilities of each mine type.

Each breaching asset is assigned a probability (reliability) that it will successfully neutralize each mine type it encounters, and a probability (survivability) that if it encounters a given mine type that it will survive that encounter. Table C1 contains reliability (R) and survivability (S) probabilities.

Breaching Asset Reliability / Survivability Probabilities

Breaching Asset	Magnetic Influence Mine (R/S)	Tilt-rod Mine (R/S)	Pressure Mine (R/S)
Mk 105	95/90		
LCAC with Line Charge		80/*	80/*

Table C1. Reliability/Survivability Probabilities for Traditional Breaching Assets. The Star (*) Represents the Fact that Once a Line Charge is Expended, it Cannot be Reused. Probabilities Expressed as Percentages.

Each landing craft is assigned a probability (activation) that it will activate a given mine type if such a mine is encounter, and a probability (kill) that, if activation occurs, the particular landing craft will be killed. Table C2 contains activation (A) and kill (K) probabilities for each landing craft.

Mine Activation and Kill Probabilities

Landing Craft	Magnetic Influence Mine (A/K)	Tilt-Rod Mine (A/K)	Pressure Mine (A/K)
AAV	70/40	75/60	75/65
LCAC	60/30	50/50	70/50

Table C2. Mine Activation and Kill Probabilities (Expressed as Percentages)

Finally, Table C3 contains the probability that each mine type will fail to activate if encountered by a breaching asset or a landing craft (dud probability).

Mine Dud Probabilities

Mine Type	Dud Probability
Magnetic Influence Mine	4
Tilt-Rod Mine	3
Pressure Mine	4

Table C3. Mine Dud Probabilities (Expressed as Percentages)

APPENDIX D. DATA AND SUMMARY STATISTICS

This appendix contains a detailed listing of the data collected from the Janus combat simulation runs in Tables D2, D3, and D4. It also contains summary statistics of this data. Table D1 lists the summary statistics.

Total LF Kills

	Bull	Traditional	ALUV
Mean	20.6	12.6	6
Median	20	12.5	5.5
Variance	7.58	7.33	4.93

Total LF Killed by MGM

	Bull	Traditional	ALUV
Mean	7.19	2.31	1.38
Median	8	2.5	1
Variance	4.43	2.5	1.58

Total AAV Kills

	Bull	Traditional	ALUV
Mean	14.5	9.19	4.63
Median	14	9	4
Variance	5.6	2.83	3.18

Total LF Killed by T-RM

	Bull	Traditional	ALUV
Mean	6.63	2.81	1.13
Median	7	3	1
Variance	4.52	3.36	1.32

Total LCAC Kills

	Bull	Traditional	ALUV
Mean	6.125	3.375	1.375
Median	6	3.5	1
Variance	3.45	2.917	0.917

Total LF Killed by PM

	Bull	Traditional	ALUV
Mean	6.8	7.4	3.5
Median	7	7	3
Variance	3.4	4	4

Total ALUV/Mine Kills

	Mean	Median	Variance
ALUV Scenario	341.81	343.5	17.76

Table D1. Summary Statistics

Bull Scenario Data

	Total Kills				AAV Kills				LCAC Kills				LCAC Kills (Inbound)				LCAC Kills (Outbound)			
	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**
Run 1	8	5	4	**17**	7	3	1	**11**	1	2	3	**6**	1	2	1	**4**	0	0	2	**2**
Run 2	8	5	8	**21**	6	3	3	**12**	2	2	5	**9**	1	1	2	**4**	1	1	3	**5**
Run 3	8	9	8	**25**	5	8	6	**19**	3	1	2	**6**	1	1	1	**3**	2	0	1	**3**
Run 4	8	5	5	**18**	6	3	3	**12**	2	2	2	**6**	1	0	1	**2**	1	2	1	**4**
Run 5	3	9	6	**18**	3	8	3	**14**	0	1	3	**4**	0	1	2	**3**	0	0	1	**1**
Run 6	10	7	8	**25**	8	5	4	**17**	2	2	4	**8**	1	2	2	**5**	1	0	2	**3**
Run 7	8	4	6	**18**	7	4	3	**14**	1	0	3	**4**	0	0	2	**2**	1	0	1	**2**
Run 8	5	7	8	**20**	3	5	5	**13**	2	2	3	**7**	1	1	2	**4**	1	1	1	**3**
Run 9	7	6	8	**21**	6	2	5	**13**	1	4	3	**8**	1	1	2	**4**	0	3	1	**4**
Run 10	3	9	8	**20**	3	9	5	**17**	0	0	3	**3**	0	0	1	**1**	0	0	2	**2**
Run 11	9	10	5	**24**	8	6	3	**17**	1	4	2	**7**	1	2	0	**3**	0	2	2	**4**
Run 12	10	3	8	**21**	9	2	5	**16**	1	1	3	**5**	0	0	2	**2**	1	1	1	**3**
Run 13	8	4	6	**18**	5	4	4	**13**	3	0	2	**5**	1	0	2	**3**	2	0	0	**2**
Run 14	6	8	5	**19**	5	6	1	**12**	1	2	4	**7**	1	1	2	**4**	0	1	2	**3**
Run 15	6	8	11	**25**	5	8	3	**16**	1	0	8	**9**	1	0	4	**5**	0	0	4	**4**
Run 16	8	7	5	**20**	7	6	3	**16**	1	1	2	**4**	0	0	2	**2**	1	1	0	**2**

Table D2. Bull Scenario Data

Traditional Scenario Data

	Total Kills				AAV Kills				LCAC Kills				LCAC Kills (Inbound)				LCAC Kills (Outbound)			
	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**
Run 1	3	4	11	**18**	2	3	6	**11**	1	1	5	7	0	0	2	**2**	1	1	3	**5**
Run 2	5	3	7	**15**	4	2	3	**9**	1	1	4	**6**	1	0	1	**2**	0	1	3	**4**
Run 3	4	1	6	**11**	4	0	5	**9**	0	1	1	**2**	0	1	1	**2**	0	0	0	**0**
Run 4	4	3	6	**13**	4	3	2	**9**	0	0	4	**4**	0	0	1	**1**	0	0	3	**3**
Run 5	1	3	10	**14**	1	2	7	**10**	0	1	3	**4**	0	1	2	**3**	0	0	1	**1**
Run 6	2	1	7	**10**	1	1	5	**7**	1	0	2	**3**	1	0	1	**2**	0	0	1	**1**
Run 7	0	2	5	**7**	0	2	3	**5**	0	0	2	**2**	0	0	1	**1**	0	0	1	**1**
Run 8	1	2	11	**14**	1	1	9	**11**	0	1	2	**3**	0	1	0	**1**	0	0	2	**2**
Run 9	0	3	6	**9**	0	3	6	**9**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Run 10	2	0	10	**12**	2	0	6	**8**	0	0	4	**4**	0	0	2	**2**	0	0	2	**2**
Run 11	3	3	5	**11**	3	3	4	**10**	0	0	1	**1**	0	0	1	**1**	0	0	0	**0**
Run 12	0	5	7	**12**	0	5	3	**8**	0	0	4	**4**	0	0	2	**2**	0	0	2	**2**
Run 13	2	8	6	**16**	2	5	5	**12**	0	3	1	**4**	0	3	0	**3**	0	0	1	**1**
Run 14	4	2	8	**14**	3	2	5	**10**	1	0	3	**4**	1	0	0	**1**	0	0	3	**3**
Run 15	3	3	7	**13**	2	3	5	**10**	1	0	2	**3**	1	0	1	**2**	0	0	1	**1**
Run 16	3	2	7	**12**	2	2	5	**9**	1	0	2	**3**	1	0	2	**3**	0	0	0	**0**

Table D3. Traditional Scenario Data

ALUV Scenario Data

	Total Kills				AAV Kills				LCAC Kills				LCAC Kills (Inbound)				LCAC Kills (Outbound)			
	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**	MGM	T-RM	PM	**Total**
Run 1	0	0	3	**3**	0	0	3	**3**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Run 2	1	3	4	**8**	0	3	2	**5**	1	0	2	**3**	0	0	0	**0**	1	0	2	**3**
Run 3	1	1	3	**5**	1	1	2	**4**	0	0	1	**1**	0	0	0	**0**	0	0	1	**1**
Run 4	2	2	3	**7**	2	2	2	**6**	0	0	1	**1**	0	0	0	**0**	0	0	1	**1**
Run 5	1	1	7	**9**	1	1	5	**7**	0	0	2	**2**	0	0	1	**1**	0	0	1	**1**
Run 6	1	2	4	**7**	0	1	3	**4**	1	1	1	**3**	0	0	0	**0**	1	1	1	**3**
Run 7	0	3	7	**10**	0	3	5	**8**	0	0	2	**2**	0	0	0	**0**	0	0	2	**2**
Run 8	3	0	1	**4**	3	0	1	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Run 9	0	0	2	**2**	0	0	1	**1**	0	0	1	**1**	0	0	1	**1**	0	0	0	**0**
Run 10	1	1	3	**5**	1	1	1	**3**	0	0	2	**2**	0	0	2	**2**	0	0	0	**0**
Run 11	3	0	3	**6**	3	0	3	**6**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Run 12	0	3	3	**6**	0	1	3	**4**	0	2	0	**2**	0	1	0	**1**	0	1	0	**1**
Run 13	1	0	4	**5**	1	0	3	**4**	0	0	1	**1**	0	0	0	**0**	0	0	1	**1**
Run 14	3	1	1	**5**	3	1	0	**4**	0	0	1	**1**	0	0	0	**0**	0	0	1	**1**
Run 15	4	0	1	**5**	3	0	1	**4**	1	0	0	**1**	0	0	0	**0**	1	0	0	**1**
Run 16	1	1	7	**9**	1	1	5	**7**	0	0	2	**2**	0	0	0	**0**	0	0	2	**2**

Table D4. ALUV Scenario Data

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